CHAPTER 4
TECHNOLOGY ASSESSMENT

The purpose of this chapter is to assess state-of-the-art of surveillance sensor and communication technologies with respect to their applicability to the l-95 Corridor Coalition's surveillance needs. This assessment covers existing and emerging technologies within the U.S. and abroad.

The assessed technologies fall within two general areas: sensor and communication. The former includes traffic detectors, weight sensors, and environmental sensors. The latter includes various methods for transferring surveillance data from a sensor to a field controller or directly to a control center, and from a field controller to a control center. The information sources used in this task include existing studies and published literature on such technologies. In some cases, interviews with vendors and public agencies were conducted to supplement the existing information.

This chapter is contains six other sections as follows:

+ Section 4.1 describes the criteria used as guidelines for the technology assessment.
+ Section 4.2 provides a review and assessment of existing sensor technologies.
+ Section 4.3 contains a review of surveillance Research and Development (R&D) efforts in the U.S. and abroad.
+ Section 4.4 contains a detailed discussion of the surveillance technology performance versus cost analysis.
+ Section 4.5 discusses existing and emerging communication technologies in surveillance, including standards and protocols.
+ Section 4.6 summarizes the assessment results.

4.1 TECHNOLOGY ASSESSMENT CRITERIA

Eight criteria were developed to assess the suitability of various detection and surveillance technologies for a Corridor-wide surveillance system. Because the available information on the technologies considered for this Project (both existing and emerging) is not sufficient to address all criteria, our approach is to assess each technology based on as many criteria as possible. This assessment will contribute to the system's conceptual design, as discussed in Chapter 5, and to development of the business plan for field operational tests and deployment, as discussed in Chapter 8 of this report. The assessment criteria are as follows.

4.1 1 Functionality

The Functionality criterion determines the ability of the technologies to support the identified Corridor-wide surveillance goals and objectives (refer to Chapters 2 and 3). The following items should be considered:

+ Potential areas of application (e.g., incident detection and verification).
+ Types of data provided.
+ Data processing requirements to obtain the desired surveillance parameters.

4.1.2 Communication Requirement

The communication requirement refers to the ability of the technology to transmit data to (e.g., commands) and receive data from other systems for use in a particular application. The following considerations are important:

+ Interfaces with local controllers (existing and future).
+ Interfaces with remote control systems [e.g., at a Traffic Operations Center (TOC)].
+ Compatibility with current and planned communications systems.

4.1.3 Installation Requirement

The installation requirement criterion provides insight to the initial effort and relative cost required to deploy the technology, and the installation's impact to the pavement. The following items need to be assessed:

+ Pavement impacts (cutting and drilling).
+ Traffic disruption (lane closure and duration of closure).
+ Mounting structure and equipment.
+ Power supply.
+ Initial calibration (detection zone location and tuning).

4.1.4 Maintenance Requirement

Maintenance requirement information is very sparse, especially for emerging technologies. Thus, this assessment also relied on the study team's experience with similar technologies. Key aspects of maintenance requirement assessment are:

+ Traffic disruption (in space and time).
+ Preventive maintenance period (cleaning, recalibration, or adjustment)..
+ Failure monitoring features.
+ Special personnel skills.
+ Special equipment.

4.1.5 Operational Environment

Since the operational environment directly affects the performance and "survivability" of surveillance equipment, the susceptibility of the equipment to a variety of environmental factors should be assessed. These factors, both natural and man-made, include:

+ Weather effects (wind, humidity, temperature, and snow).
+ Traffic effects (vibration, turbulence, weight, and size).
+ Roadway infrastructure effects (tunnels and draw bridges).

- Terrain effects (line of sight and multipath).
- Lighting effects (day, night, cloud, and shadow).
- Electromagnetic interference.
- Pollution effects (vehicle emissions, dust, and other airborne particulates).
- Wildlife effects (birds, insects, and other animals).

4.1.6 Demonstrated Capability and Performance

Information on the demonstrated capability and performance of emerging technologies is very limited. The purpose of this criterion, therefore, is then to find out how much a technology has been tested and/or used in transportation and other domains. Search and review of the following types of information for the candidate technologies were conducted:

- Test results (laboratory and field).
- Existing level of deployment.
- Experience in other domains.

4.1.7 Anticipated Relative System Cost by Application

Although an accurate cost assessment is not possible without a system design, some idea of the relative cost of candidate technologies is necessary. For each potential application, the relative cost assessment focused on three items:

- Direct cost [capital and Operations and Maintenance (O&M)].
- Indirect cost (traffic disruption caused by installation, maintenance, and repair).
- Relative cost.

The direct costs for existing technologies were based on estimates available in the literature. The indirect costs were based on estimates of the installation and maintenance requirements of the technology. The relative costs were based on a comparison with the cost of existing systems (e.g., inductive loop detectors).

4.1.8 Availability

The anticipated availability of technology for deployment influences the conceptual system design and the development of the business plan. For existing technologies, information from suppliers was collected to the extent possible. For emerging technologies and those being developed, estimates on Initial Operating Capability (IOC) were reported, if available. Thus, the assessment of technology availability focused on:

+ Technology suppliers for existing products.
+ Expected IOC for emerging technologies based on:
    - Field operational test results.
    - Applications in other domains.
    - Available R&D plans from developers.

4.2 EXISTING SURVEILLANCE TECHNOLOGY

This section describes the characteristics of various existing vehicle detection, WIM, and environmental sensors. The description considers the functional characteristics, associated communications requirements, and installation considerations of each of the sensor types. Particular advantages, disadvantages, and functional limitations of the sensor technologies are also described. The detection technologies assessed in this study include:

+ Inductive loop detectors.
+ Magnetic detectors and Magnetometers.
+ Sensing cable/pressure and bending plates.

- Infrared/photoelectric detectors.
- Acoustic detectors.
- Microwave radar detectors.
- Vehicle probes.
- Video vehicle detection systems.
- Bending plate systems.
- Shallow weigh scales.
- Deep-pit weigh scales.
- Bridge weighing system.
- Capacitive systems.
- Piezo-electric sensors.
- Fiber-optic sensors.
- Surface Conditions Analyzer (SCAN), Light Detection And Ranging (LIDAR), and the HANDAR™ environmental sensor.

4.2.1 Vehicle Detection Technologies

A significant number of alternative detection technologies are available for traffic surveillance application. The following is a brief discussion of these types in terms of functionality and application considerations. A detailed discussion of the existing detection technologies, including loop detectors, magnetic detectors, and magnetometers may be found in the Traffic Defector Handbook [FHWA, 1990]. This handbook describes the principles of operations, design considerations, and installation and maintenance procedures for these detectors. A summary of this information is provided in Table 4-1. For the existing (commercially available) detectors, Table 4-2 [Hughes Aircraft Company, 1994] shows the specific manufacturers and models of various detector technologies with the data provided by the sensors, and acceptable operating environments.

DETECTOR	INSTALLATION		MANUFACTURERS
Self-Tuning Inductive Loop	Under Pavement	i loop. numbers. coefficient id	+ AVE + Detector Systems + EMX Inc. ♦ Indicator Controls Corp. ● Microsense Sarasota ♦ Signal Installation and Repair ♦ 3m/Canoga
Magnetic Probe	Under Pavement	rs on and	♦ Decatup Electronics Inc. ♦ M-Systems ♦ Teeco Safety Inc. ♦ 3M/Canoga
Sensing Cable	Under-Pavement	rs	♦ Atochem ♦ Focas Ltd.
Loop Mat	On-Pavement	itable for	♦ Gates Rubber Co.
Pressure Plate	On-Pavement	rs	
Magnetometer	On-Pavement	e cabinet.	
Infrared, Active	Over-Pavement	and conditions ation	♦ Microsense ♦ Truvelo
Infrared, Passive (lane)	Over-Pavement		
Infrared, Passive (area)	Over-Pavement		
Ultrasonic-Continuous Wave	Over-Pavement		
Ultrasonic-Pulsed	Over-Pavement	inaccuracies	♦ HB Detection ♦ Sumitomo Electric Industries, Ltd.
Passive Sonic	Over-Pavement	ences	
Radar	Over-Pavement	n	♦ HB Detection ♦ Lux Traffic Controls Ltd. ♦ Sensy Traffic Ltd. ♦ Whelen Engineering Co.
Machine Vision	Over-Pavement		♦ Econolite ♦ Rockwell

Detector Techology and Model \ Traffic Parameter	Data							Environment						Other	
	Count	Presence	Speed	Speed Binning	Occupancy	Vehicle Class	Incident Detection	Detection Range	Rain	Fog	Snow	Day	Night	Availability	Interfaces Specified
Ultrasonic															
Sumitomo SDU 200	X		X		I	L	I	X	X	X	X	X	X	X	X
Sumitomo SDU 300	X	X			X		I	X	X	X	X	X	X	X	X
Microwave Sensor TC-30	X	X			I		I	X	X	X	X	X	X	X	X
Microwave Sensor	X	X			I		I	X	X	X	X	X	X	X	X
Infrared (Active)															
Schwartz Electro-Optics	X	X	X		I	X	I	X	?	?	?	X	X	X	X
Infrared (Passive)															
Eltec 842	X	X			I		I	X	?	?	?	X	X	X	X
Eltec 833	X						I	X	?	?	?	X	X	X	X
Microwave Radar															
Microwave Sensors TC-20	X							X	X	X	X	X	X	X	X
Microwave Sensors TC-26	X		X	X			I	X	X	X	X	X	X	X	X
Microwave Sensors TC-31		X						X	X	X	X	X	X	X	X
Whelen TDN-30	X		X				I	X	X	X	X	X	X	X	X
Whelen TDW-10	X		X				I	X	X	X	X	X	X	X	X
Electronic Integ System RTMS	X	X	X		X		I	X	X	X	X	X	X	X	X
Video Image Processing															
Hughes Video Detection System	X	X	X	X	X		X	X	?	?	?	X	X	X	X
Hughes Hywayman	X	X	X	X	X	X	X	X	?	?	?	X	X	X	X
Autoscope 2003	X	X	X	X	X	I	X	X	?	?	?	X	X	X	X
Computer Recog System TAS	X	X	X	X	X	I	X	X	?	?	?	X	X	X	X
Inductive Loop Detectors	X	X	I		X		I	X	X	X	X	X	X	X	X
Magnetometers	X	X	I		X		I	X	X	X	X	X	X	X	X

Legend:

X Data that are measured directly, acceptable operating environments, or other conditions that are satisfied.

I Information available through processing of detector data (i.e., indirectly available information).

L Vehicle length data availability.

? A possible degradation in performance dependent on the severity of the environment.

Source: [Hughes Aircraft Company, September 1992]

4.2.1.1 Inductive Loop

General Characteristics

Conventional loop detectors are relatively simple devices, consisting of multiple (usually 3 to 5) turns of wire embedded in the traveled lanes of the roadway. When connected to a suitable detector loop amplifier which excites the loop at a particular frequency, an electro-magnetic field is set up in the immediate vicinity of the loop. A large metal object (vehicle) passing over the loop changes the properties of this field. This change is registered as a detection by the detector loop amplifier, which together with the loop itself, is commonly referred to as a Vehicle Detector Subsystem (VDS). The VDS, when interfaced through a local field controller, provides measurements of traffic parameters, such as occupancy and speed, to a central traffic management system.

Detector amplifiers are commonly distinguished on the basis of the number of individual loops which the detector amplifier operates. Detector amplifiers may operate in conjunction with one loop (one channel), two loops (two channel), or four loops (four channel).

Two- and four-channel loop detector amplifiers may use either sequential loop scanning or distinct loop excitation frequencies to prevent crosstalk between adjacent loops from causing false detections. The detector amplifier unit allows for adjustment of sensitivity on individual channels, requiring a calibration process to be completed following installation of the VDS before the loop data can be used effectively.

The detectors themselves are mounted at a designated separation distance along the traveled roadway, with the amplifiers and field controller installed in an environmentally controlled roadside cabinet. The field controller is, in turn, connected using the appropriate interface to a communication system, such that a central traffic management computer can communicate with the field controller to receive traffic data.

Another type of loop detector, intended only for temporary installations, is the loop mat detector. The loop mat detector operates in the same manner as conventional saw cut installed loop detectors. The detector consists of a durable rubber mat in which a multiple turn loop is embedded. The detector makes use of the same ancillary equipment, including a loop detector amplifier. This type of detector, because it is placed on the pavement, is intended for temporary use only.

Depending on the requirements of the traffic data processing algorithms, loop detectors are sampled by the local field controller at a rate between 60 Hz and 240 Hz. Loops are sampled by the field controller at a set rate. Raw data may be transmitted to the control center, requiring no special field data processing; or data may be processed locally to generate average vehicle occupancy, volume, speed, and aggregate vehicle classification data for transmission to the control center. Such processing usually includes checking for loops generating bad data: stuck-on, stuck-off, or oscillating (chattering). The minimum communication requirements for vehicle detector stations are limited to a voice-grade channel for communication between the local controller and the traffic management system and operating at 1200 to 9600 bps full duplex. Depending on the available communication medium and the channel data rate between the local field controllers and the central traffic management system, data from several controllers may be transmitted on a single channel.

Calibration of the loop detector and corresponding amplifier are required upon installation to ensure that the loop is functioning properly and that surrounding structures do not adversely affect the loop's operation. Maintenance of the loop detectors is not considered, because they must be replaced if a failure occurs. A common replacement number of 5 percent over the course of one year is used to estimate replacement cost.

Installation of Conventional Loop Detectors

Most conventional loop detectors are installed using a cut-and-wind process. A narrow saw cut in the shape (usually square, rectangular, or diamond) of the loop is made in the top course of existing pavement or in the base course of new pavement. Then, the slot is cleaned thoroughly and all sharp edges are chamfered. The detector loop is formed by winding a specified number of turns of 14 to 18 AWG insulated wire into the slot, and sealing the slot with epoxy or rubberized asphalt. Often, a backer rod or other bedding is installed over the wire to hold it to the slot bottom during sealing and to help protect it from stones or other protrusions.

Installing loop detectors using the cut-and-wind procedure is relatively simple, requiring only a pavement cutter, cleaning apparatus, the loop wire (and backer rod if used), and sealant. A typical

6-foot by 6-foot freeway loop takes 30 to 45 minutes to install. Special care must be taken to ensure that the slot is absolutely clean and free of sharp protrusions. Poorly cleaned or chamfered slots often result in damaged loops.

Installation of Pre-formed Loop Detectors

Pre-wound/pre-formed detector technology seeks to overcome some of the problems associated with conventional cut-and-wind loops. The loops are pre-wound at the factory (to the client's specifications) and may be enclosed in conduits of the desired dimensions (pre-formed). They can be cut into existing pavement (as with conventional loops), tied to reinforcing steel prior to pouring concrete, or directly paved over for new construction or overlay work.

The use of a conduit provides added protection against both penetration (from stones or sharp edges) and water ingress. Slot preparation (for cut loops), although still important, becomes less critical for proper loop operation. The disadvantage is that a significantly wider slot (relative to conventional loop installation) is cut, requiring more sealant, and increasing the susceptibility of sealant deterioration.

Pre-formed loops offer the greatest advantage for new or overlay pavement construction. In this case, no cut is required; and installation time is significantly reduced. The loops can be placed in the desired configuration prior to asphalt or concrete placement. Pre-formed loops available on the market are designed to withstand a considerable amount of abuse during installation. If properly bedded, they should be able to survive inadvertent run-over by pavers, concrete trucks, and such, during the construction process.

Loop Detector Configurations

Three main loop shape alternatives can be considered for vehicle detection application (for both conventional and pre-formed loops): rectangular and square loops, diamond loops, and circular loops [Morris, 1978]. Rectangular/square loops are susceptible to cross-talk and adjacent lane pick-up, as well as to interference from reinforcing steel. However, lane cross-talk can be used to advantage when applied to one lane ramps to detect vehicles partly on a shoulder. Rectangular loops, because of their right angle corners, are somewhat susceptible to deterioration under heavy loads. During installation, efforts to eliminate the sharp-edged corners will help to prevent damage to the loops.

Diamond loops are configured so that the wires of the loop do not run parallel to the nearest wires of adjacent loops within the same lane or in adjacent lanes. As a result, diamond loops are less susceptible to cross-talk between loops than are rectangular loops. Furthermore, the loop edges do not run parallel to reinforcing steel, making them less susceptible to this type of interference. Another advantage of diamond loop configurations is that the corners of the diamond loop produce a concentrated (high flux density) magnetic field. Accordingly, this configuration facilitates precise determination of both vehicle entry and departure from the detector zone. However, as with rectangular loops, diamond loops incorporate sharp corners where deterioration may become evident under heavy loads.

Circular loops offer many of the advantages of diamond loops in terms of low susceptibility to both cross-talk and interference from reinforcing steel. A more uniform and well-defined field pattern (detection zone) can be achieved in this configuration with minimal field spill-over beyond the loop boundaries. By eliminating all sharp corners, circular loops are made less susceptible to deterioration. Furthermore, the installation method using a circular cutter can result in a significant reduction in installation time and associated traffic closure requirements.

Advantages and Disadvantages

A major advantage of inductive loop detectors is the extensive experience with the technology and its proven effectiveness. Inductive loops provide good presence detection, and the size and shape of the detection zone can be customized.

The principal disadvantages of inductive loop detectors are not related to the sensor unit, but to the wire installation itself. These primary disadvantages include the following:

+ Susceptibility to degradation in deteriorating pavements.
+ The quality of installation significantly impacts detection accuracy.
+ The life span of the detector is limited by the pavement life span.

+ A tendency to double count trucks.

+ Lane closure is required for installation.

4.2.1.2 Passive Magnetic Detectors and Magnetometers

Unlike inductive loop detectors, passive magnetic detectors do not create a magnetic field, and operate on the basis of detecting a change in the lines of flux from the Earth's magnetic field [FHWA, 1990]. When a vehicle nears or passes over a passive magnetic detector, the constant lines of flux passing through its coil are deflected by the vehicle, causing an induced voltage in the coil. A high-gain amplifier enables this voltage to operate a relay, triggering a vehicle detection to the controller.

Passive magnetic detectors are not suitable for detecting vehicle presence, since they require a minimum vehicle speed of 3 to 5 mph for detection. Passive magnetic detectors are also responsive to flux changes over a large area, covering up to three traffic lanes.

Magnetometers are passive devices which sense changes in the Earth's magnetic field. When a large metal object (such as a vehicle) passes over the detector, a change in the Earth's magnetic field is induced. This change is registered as a detection. As with inductive loop detectors, the magnetometer transducer signal is conditioned by an amplifier, typically connected to a local field controller.

Magnetometers are very effective point detectors and are used in toil facilities and parking structures which require an indication that a vehicle has reached a specific point. This type of detector is also well suited for vehicle count applications with minimal vehicle separation, since the magnetometers can be placed closely. A pair of successive magnetometers may be used to determine vehicle count, speed, length, and occupancy (e.g., using a proprietary system of magnetometers known as the Hi-Star Traffic Analyzer). However, since magnetometers typically are not able to provide a consistent response time to vehicle entry or departure from the detection zone, due to the natural continuous variation of the Earth's magnetic field, the relative accuracy of vehicle speed and occupancy measurements is typically less than that obtainable from other systems.

Also magnetometers are used commonly in bridge decks where the reinforcing steel structure interferes with the operation of an inductive loop. As passive devices, magnetometers are not susceptible to such interferences or crosstalk from adjacent detectors; although, as for loop detectors, accurate performance requires calibration.

Usually the detector unit is installed in a pre-drilled hole in the road surface, making installation of magnetometers significantly simpler than for inductive loops. The detector is connected to the roadside equipment using lead-in cabling (as with inductive loop detectors), or using a radio link [e.g., the Self-Powered Vehicle Detector (SPVD)] to communicate with a field controller [FHWA, 1985, FHWA 1990]. Magnetic detector data communication requirements are similar to the requirements for inductive loop detectors. Also, the probe and polyurethane-jacketed lead-in wires are, relative to inductive loops, less susceptible to effects stemming from pavement deterioration.

Magnetic detectors and magnetometers are similar to inductive loop detectors in that the probe senses a change in the magnetic field and records that change as a passing vehicle. Maintenance is slightly easier, because this type of detector is installed by drilling a hole in the pavement; but a cable slot must be installed between the roadside junction box and the probe for the magnetic detector. Therefore, a lane must be closed for installation or maintenance. Given the high maintenance cost and the minimal return in data, the magnetic detector is to be used even less often than the inductive loop detector. Magnetometers are probably the most suitable detector for use along entrance ramps for ramp metering.

4.2.1.3 Sensing Cable/Pressure Plates and Bending Plates

A sensing cable consists of a piezo-electric polymer mounted within or on the pavement and producing an electrical signal when compressed by the passage of a vehicle's wheels [Moralee, 1988]. Pressure plates are installed on the pavement and register vehicle presence when the vehicle's weight closes electrical contacts. Bending plates measure the deflection of a beam from the axle load, using strain gages mounted to the bending plate. The communications requirements for these sensor types are similar to the requirements for loop detectors.

Because these detectors sense vehicle axles, speed and occupancy cannot be measured directly; and estimates of volume are calculated with relatively poor accuracy. Another disadvantage is that all of these sensors are subject to mechanical stresses associated with measuring vehicle axle weight, limiting their usable life span. However, they can provide vehicle classification information based on axle weight. One primary advantage of surface mounted sensing cables and pressure plates is that they are relatively easy to deploy, providing traffic data at minimal cost.

4.2.1.4 Infrared/Photoelectric Detectors

Infrared (IR) vehicle detection systems, comprising both passive and active sensor types, provide vehicle presence, speed, and other traffic parameters. An active system transmits a low-power IR signal which is reflected by vehicles in the sensor's detection zone. The reflected signal is received by the sensor and focused by an optical system onto a detector matrix [Hughes Aircraft Company, 1994; Duckworth, et. al., 1994]. Active sensors, depending on their design, can provide IR thermal imaging capability. In non-imaging systems, vehicle presence causes a change in the energy level of the reflected IR signal, relative to the background reflection level. In imaging sensors, the detector matrix represents the two-dimensional IR image defined by the field of view of the receiver optics (the detection zone). The image is processed in a manner similar to video image processing; that is, the signal processing algorithms analyze changes in the received energy level (pixel intensity) associated with a vehicle moving into the field of view of the sensor.

Active IR detectors provide vehicle presence, count, and speed data, and are capable of providing vehicle length and queue length data. However, the performance of active IR detectors is degraded by bad weather, since precipitation will absorb and scatter IR energy, affecting the received energy level at the sensor. In addition, direct sunlight or reflected sunlight directed at the sensor will also affect the received IR energy level at the sensor, causing false detections.

Passive IR detection systems sense the temperature gradient between the vehicles and the roadway or ambient environment. These sensors operate on the principle that any warm subject emits energy in the IR range. The frequency and intensity of the emitted IR radiation depend on a number of influencing parameters, including the emissivity of the vehicle and road surface, and their surface temperatures. Passive IR detectors consist of an IR sensor for receiving IR radiation, coupled with an amplifier and an evaluation unit. These sensors can provide vehicle count data, and more sophisticated passive IR imaging sensors can provide vehicle classification data. Such systems may be particularly valuable to truck safety enforcement, with the ability to detect overheating and faulty brakes [California Polytechnic State University, 1994]. Typically, IR sensors are mounted overhead or at the side of the roadway.

Since passive IR detectors only detect changes in the intensity of the received IR radiation, the target vehicle must move through the detector field of view at some minimum speed to be detected. However, passive IR sensors are not capable of providing vehicle speed or vehicle presence detection; because stopped vehicles cannot be detected.

IR sensors can be mounted overhead or at the side of the roadway, offering an advantage in reducing traffic disruption during installation and maintenance. The overhead mount configuration with one detector per lane is preferred, because this configuration can minimize the environmental effects (e.g., lightning, rain, snow, and fog).

Some sensors using IR are equipped with retroreflectors. The sensors are mounted overhead and aimed downward at a small angle toward a retroreflector on the pavement in the center of a traffic lane. The retroreflectors must be sturdy, because tires will run over them. Retroreflectors made of hollow plastic, three inches in diameter, secured to the pavement with epoxy, and surrounded by two layers of asphalt roofing shingles have worn well.

Sensors may be mounted beside traffic lanes. The sensors' light beams may be aimed to detect the presence of a vehicle's body, chassis, or load. However, since the shape, size, and vertical position of these vehicle components vary widely, it may be difficult, or even impossible, to aim a single light beam to detect every vehicle.

Additionally, sensors may be located at the edge of the traffic lane, on the shoulder, or beyond. The light beam may be aimed just above the pavement surface to detect the presence of a tire. For counting axles, a single light beam at a right angle to the direction of traffic flow is adequate. Two such beams set apart at a known distance longitudinally can be used to measure speed.

IR sensors may also be photoelectric sensors. This type of sensor consists of an IR light source (which may also be a laser light source) and a receiver which detects and evaluates the emitted IR light. Photoelectric sensors can be arranged to detect the presence or absence of a vehicle tire or of a vehicle body, chassis, or load with respect to time and location in space. Thus, vehicles or axles can be counted; vehicle speed can be measured; the number of axles per vehicle can be determined; spacing between successive axles on a moving vehicle can be calculated; single or dual tires can be distinguished; the approximate size of the tire-to-pavement contact area can be estimated; and the overall dimensions of the moving vehicle body can be calculated.

To ensure the performance of a photoelectric sensor, the IR emitter and receiver must be accurately aligned to avoid reflection interference. Furthermore, the sensor must be cleaned frequently because dirt, vehicle emissions, and other substances in the roadway environment can greatly degrade sensor performance.

The communication requirements for these sensors are few, as for loop or magnetic detectors.

4.2.1.5 Acoustic Detectors

Active Acoustic Detectors

Most active acoustic detectors are ultrasonic. They operate in a frequency range from 30 KHz, to 100 KHz and consist of an ultrasonic transmitter and receiver, and a processor unit. The transmitter and receiver are often packaged as an ultrasonic transducer. The ultrasonic transducer, which is mounted overhead, transmits ultrasonic waves. These waves are reflected off of a vehicle in the detector's field of view, or off of the background. Then, the waves are received by the transducer. The ultrasonic signal may be transmitted in a continuous wave or in pulses. Three methods of detection are used: Continuous Wave (CW) Doppler for speed measurements only; pulse-mode Doppler which measures presence, count, and speed; and pulsed ultrasound ranging, which measures of presence, count, and vehicle classification.

CW Doppler ultrasonic detectors operate in a manner similar to a Doppler radar: an oncoming vehicle will cause the reflected ultrasonic signal to increase in frequency by a predictable function of the vehicle's speed, the observation geometry, and the ultrasonic detector's operating frequency. Similarly, as a vehicle recedes from the detector, the reflected frequency decreases. This type of detector is mounted above a roadway and is aimed at the oncoming traffic, typically with an angle of incidence of 45 degrees. Because the detector senses only the shift in frequency, this type of detector measures speed only; and no presence detection is possible.

Pulse-mode Doppler ultrasonic detectors emit short bursts of ultrasonic energy, allowing range and speed to be measured. Speed is measured using the Doppler effect. Range is measured by timing the transmission and arrival of the pulses. As with CW Doppler detectors, pulse-mode Doppler ultrasonic detectors are mounted above travel lanes and aimed with a 45 degree angle of incidence at the oncoming traffic. The presence of a vehicle in the field of view decreases the elapsed time between transmission and reception of an ultrasonic signal. Because both range and speed measurements are possible with this type of sensor, vehicle presence, count, and speed parameters are available. Some degree of classification is available if the detector is mounted directly over the roadway, because the round-trip time from transmitting to receiving indirectly measures the height of the vehicle.

Like pulse-mode Doppler detectors, pulsed ultrasound detectors emit short bursts of energy to allow measurements of range; but the detectors do not detect the Doppler frequency shift from moving vehicles, and cannot measure speed. This type of detector is mounted directly over travel lanes and is aimed directly down at the roadway. In this manner, the travel time of the transmitted pulses can be measured and converted to a range measurement. If no vehicles are present, the range measurements correspond to the distance between the sensor and the roadway. When a vehicle passes beneath the sensor, the range measurements decrease corresponding to the height of the vehicle. Hence, vehicle presence, count, and classification may be obtained from this sensor type.

The performance of all of these active acoustic sensors is affected by prevailing atmospheric conditions. The speed of sound in air depends mainly on the ambient temperature, but barometric pressure fluctuations can also influence the accuracy of ultrasonic detectors. Measurement accuracy can be derived from data relating the speed of sound to atmospheric temperature and pressure, and the sensors can be designed to compensate for known variations accordingly. However, there is anecdotal evidence that ultrasonic sensors are susceptible to wind gusts and environments with high ambient noise. Furthermore, rain and snow will affect the sensor's performance. Short wavelength (high frequency) acoustic energy is reflected by the precipitation. This effect, known as backscatter, attenuates the signal reflected by the vehicles, causing missed detections. Also, backscatter may cause false detections if the reflected energy from the precipitation is detected by the sensor [Duckwork, et ***al,*** 1994]. Except in extreme conditions, these error sources can be moderated.

For many years ultrasonic detectors have been applied where poor pavement conditions are unsuitable for loop detector installation. The most extensive use of ultrasonic detectors is in Japan, where policy dictates that pavement cutting for loop installation is not permitted [Sumi, 1988]. These detectors form a major component of the traffic monitoring system in Tokyo, although current research is moving toward using IR sensors to incorporate vehicle to roadside data communication.

Pulsed ultrasonic devices must be mounted directly overhead for lanes requiring detection. For ultrasonic equipment, the large wavelength mitigates dispersion of the pulse on reflection. In turn, a vehicle surface nearly perpendicular to the pulse direction is required to receive the reflection. This unit is best placed the unit pointing down from overhead. Multipath effects (reflections) in covered roadways degrade the accuracy of the ultrasonic detectors, making deployment of these sensors inappropriate for such conditions.

As previously discussed, ultrasonic devices require overhead mounting, which makes maintenance accessibility problematic. Additionally, field controllers supporting the ultrasonic devices must be mounted directly adjacent to the device. This causes additional maintenance accessibility problems. The communication requirements for active acoustic (ultrasonic) detectors are few, as for loop detectors.

Passive Acoustic Detector Arrays

A passive acoustic detector is composed of a set of microphones (well matched in phase and amplitude) that receive audible to ultrasonic acoustic energy from vehicles. Detected vehicle noise includes both engine noise associated with combustion and moving belts, and tire/road noise. The microphones are arranged in an array, equally spaced vertically, horizontally, or both. Since sound waves propagate radially from a source, the acoustic energy will arrive at the sensor and be detected by the individual microphones in the array at slightly different times, corresponding to the distance between the microphones and the speed of sound in air. Using this principle, the sensor is able to determine the direction from which the acoustic energy emanates; that is, the microphones provide spatial directivity allowing a detection zone to be established. This also allows the sensor to reject or attenuate acoustic energy originating from locations outside of the detection zone [Hughes Aircraft Company, May 1994]. The size and shape of the detection zone are determined by the sensor aperture size, processing frequency band, and installation geometry.

Since the sound energy increases as a vehicle enters the detection zone, and decreases as it leaves the detection zone, a passive acoustic detector can provide vehicle presence output in the form of contact closures for use in calculating traffic volume, occupancy, and average speed. Using more advanced signal processing algorithms, vehicle classification is possible. However, vehicle classification based on acoustic signature is difficult when only a single vehicle is present, due to the great variability in tire/road noise associated with tire pressure, road surface, and vehicle load. Vehicle classification based on acoustic signature is significantly more complicated when the noise of other vehicles causes interference in the received signal.

The communications bandwidth requirement for passive acoustic detectors is relatively low if the signal processing is done in the field. However, if the signal processing is done centrally, requirements may increase, depending on the number of microphones in the array, the specific sampling rate used, and data compression techniques.

4.2.1.6 **Microwave Radar Detectors**

A radar (radio detection and ranging) detector consists of a transmitter, a receiver, a transmitting and receiving antenna, and an evaluation unit (or signal processor). The radar antenna emits electromagnetic waves reflected from either the background or a vehicle within the antenna's field of view. The reflected electromagnetic energy is received and processed by the radar detector. Most radar systems employ Radio Frequencies (RF) in a range from a few hundred megahertz to 100,000 megahertz (100 GHz). Radars are often identified by the characteristic RF wavelength as well. The most common designations are summarized in Table 4-3 [Skolnik, 1980]. Commercially available radar systems for traffic detection operate in frequency bands near 10.5 GHz (X-band), 24.0 GHz (K-band), and 34.0 GHz (Ka-band) because of Federal Communications Commission (FCC) regulations. All of these frequency bands are designated as microwave, so traffic detection radars are sometimes known as microwave radars.

Table* 4-3. Radio *Frequency Designation

Designation	Radio Frequency	Wavelength
Millimeter wave	30 GHz to 100 GHz	3 to 100 mm
Microwave	1 GHz to 30 GHz	1 to 30 cm
Ultra-High Frequency (UHF)	300 MHz to 1000 MHz	0.3 to 1.0 m
Very High Frequency (VHF)	30 MHz to 300 MHz	1 to 10 m
High Frequency (HF)	3 MHz to 30 MHz	10 to 100 m

Microwave radars used in traffic applications are of two types [Hughes Aircraft Company, May 1994]. The first transmits a continuous wave of electromagnetic energy. It measures the speed of vehicles in its field of view using the Doppler principle. The second type of radar transmits a saw-toothed waveform, also called Frequency Modulated Continuous Wave (FMCW), in which the transmitted frequency is constantly changing with respect to time. The FMCW radar provides the capability to measure range and, therefore, functions as a presence detector. The FMCS radar can also measure vehicle speed when the field of view in the direction of vehicle travel is divided into range bins.

To obtain range data, FMCW radars continuously vary the frequency of the microwave signal between two specific frequencies. The range to the vehicle is proportional to the difference in the frequency of the transmitter at the time that the signal is transmitted (t_1) and the time at which it is received (t_2). The range measurement is based on the frequency difference between the instantaneously transmitted and received signals. That is, with a constant rate of change of frequency, the range to an object can be determined by comparing the frequency of the received signal to the frequency of the transmitted signal. Since the frequency difference is proportional to the travel time of the signal (both to and from the vehicle), and the time difference is proportional to twice the distance between the transmitter and the vehicle, the range (distance) between the sensor and the vehicle can be calculated. Typical modulation techniques include saw-toothed, triangular, and sinusoidal waveforms [Knott, et. al., 1985; Hughes Aircraft Company,

The Remote Traffic Microwave Sensor (RTMS) manufactured by Electronic Integrated Services is a microwave-based radar detector operating in the X-band. These detectors can be either side or overhead mounted. Side-mounted units are unable to obtain lane-specific information. The units are typically mounted overhead, requiring one unit for each travel lane for which lane-specific information is required.

Microwave radar detectors may also be side mounted on a pole alongside of the roadway, approximately 30 feet above ground level. These sensor units cannot detect objects closer than 10 feet; therefore, the unit's sensor must be mounted 10 feet from the edge of the first traveled lane of the roadway. When mounted at the side of the roadway, only average roadway speed may be measured. Therefore, to obtain accurate lane-specific information, individual radar detectors must be mounted over each lane.

The performance of microwave radar sensors can be impacted by weather conditions. Rain or fog, which reduce the received signal strength, can affect detection accuracy. However, these effects can be minimized by mounting the detector in close proximity to the roadway, thereby shortening the transmission distance. Microwave radar detectors are inappropriate for deployment in covered roadways, such as tunnels.

Although microwave radars are gaining acceptance in the transportation field and existing sensors meet low-level power requirements, public reaction to increased electromagnetic radiation exposure may be negative [Duckworth, et al, 1994]. Safety issues must be addressed [Hughes Aircraft Company, May 1994].

Microwave radar requires a substantial initial installation and calibration effort to establish detection zones. Detector performance is greatly affected by surrounding structures; therefore, a detailed calibration process is required to ensure that vehicles are properly detected. However, once the system has been calibrated, no ongoing calibration procedures are required.

4.2.1.7 Video Vehicle Detection Systems

Video Vehicle Detection System (VVDS) is a machine vision technology which uses video image processing to detect vehicles and extract relevant traffic parameters from a video image. VVDS requires field camera installation, and depending on the particular functional requirements of the installation, may include field installation of the image processing equipment. The images are transferred from the camera to the microprocessor, where the image is analyzed and relevant traffic parameters are extracted.

Video vehicle detection systems are often used to perform loop emulation, providing a functional equivalent to installation of loops in the roadway. In such installations, the image processing equipment is located in the field, and the VVDS provides vehicle presence detection (occupancy) to a field controller. Using other image processing techniques, video vehicle detection systems can be used to perform scene analysis for incident detection. In such systems, the VVDS or a Video Incident Detection System (VIDS) compares a real-time video image to a static image of a section of roadway to determine whether any stopped vehicles exist in the camera's field of view. Usually, the image processing equipment for this type of installation is located at the traffic control center, requiring a communication system with sufficient bandwidth to transmit real-time video from the field to the control center.

Advances in camera technology, microprocessor capability, and image processing techniques have rendered VVDS a viable alternative for installations which presently use loop detectors. The shortcomings of loop detector technology, as described earlier, are related to their installation and to limitations resulting from the life of the pavement in which they are installed. Although detector loops are able to measure many of the important traffic parameters, when an incident is detected, it is the CCTV subsystem which is used to confirm the incident and assess its severity. Since the CCTV subsystem constitutes an integral part of a Freeway Traffic Management System (FTMS), there may be some opportunity to combine VVDS with existing infrastructure.

Vehicle detection using video imaging to emulate loop detectors is, as expected, similar to magnetic loop detection. The user must identify the required detector locations by placing markers electronically on the road lanes using a video display. The image processing system calculates the video image (pixel) intensity level of each marker. This level represents the background value used to determine vehicle presence. When a vehicle passes over the designated marker, the computer detects the presence of a vehicle and stores the time duration for which the marker is active. Special algorithms sort out actual vehicle movements from other false or non-relevant image changes, including shadows caused by trucks, changing light conditions, glare, and lane changes.

The performance of a VVDS is affected by weather and ambient lighting. Typically, performance degrades during night operation, primarily depending on the performance of the camera equipment and its “anti-blooming” capabilities to compensate for vehicle headlights. In addition, ambient lighting transitions at dusk and dawn affect the performance of the VVDS. Adverse weather conditions such as fog, dust, and heavy rain or snow limit the available sight distance and degrade the performance of the VVDS.

A VVDS requires an extensive initial set up and calibration of the equipment to define the detection zones. However, no ongoing calibration of the system is required unless the camera is relocated. Manufacturers recommend that the camera be mounted directly over the roadway (e.g., an overpass), so that the horizontal image axis is perpendicular to the direction of travel. The ideal camera elevation is 45 degrees down from horizontal. If the camera is mounted at the side of the roadway, the image aspect ratio is distorted, and the accuracy of speed measurements is reduced. For accurate speed measurements, VVDS may require knowledge of the actual distance between two detection zones set up in the image. This knowledge may be acquired by establishing the detection zones adjacent to objects (such as sign posts) appearing in the camera's field of view and measuring the actual distance between the objects. This distance is then used by the image processing system to transform the image distance (in pixels) to the actual distance (in feet or meters). In addition to distance, azimuth/orientation, and elevation calibration, VVDS systems must be calibrated to compensate for lighting.

Depending on the system architecture, extensive processing of the data gathered by the VVDS may be required in the field or at a central location. Field deployment of the image processing hardware may be more cost effective where the expense of installing communication hardware and cabling to transmit real-time video back to a control center is prohibitive. However, where existing communication capabilities allow transmission of real-time (full-motion) video, processing the images in the control center is likely to be more cost effective because fewer image processing stations are required.

Whether processing is performed in the field or at a center, a computer capable of handling one to two cameras is required. If processing is performed at a center, the video images must be brought back to that location, requiring a substantial bandwidth. If processing is performed in the field, video images only need to be transmitted to the processing point. Therefore, a low bandwidth, similar to that required by loop detectors, is needed.

Camera lens upkeep is an important part of the operations and maintenance cost. Regularly scheduled cleaning of the cameras is required.

There are a number of developing VVDS technologies that could be applied to the I-95 Corridor-wide Surveillance System (refer to Table 4-4). Since VVDSs are still undergoing evaluation by various agencies, the majority of available system information is from the manufacturer.

The most comprehensive discussion of VVDS is provided by an evaluation of eight systems (three of which are commercially available) by the California Polytechnic State University (CalPoly) in June 1991. The goal of the project was to evaluate image processing technologies and assess their applicability for highway traffic detection and surveillance. In order to assess the accuracy of the systems, measured traffic counts and speeds were compared with manually derived results.

The report states that, as a result of the multitude of tests performed under various conditions, direct comparison between systems is not possible. The results can, however, be used to illustrate the relative strengths and weaknesses of each system. A brief discussion of the reported results follows.

Table 4-4. Available VVDS Systems

System	**Minimum Hardware Requirements**	**Software Requirements**
Autoscope	- Black Box - IBM 386-Compatible Computer - Matrix Video Card - 1 Monitor	- Proprietary Software - Microsoft Windows
Camera and Computer Aided Traffic Sensor (CCATS)	- Black Box - IBM 386-Compatible - 1 Monitor	- Proprietary Software
Traffic Analysis System (TAS)	- Black Box - IBM-Compatible Computer - 1 Monitor	- Proprietary Software
Aspex Traffic Analysis System	- Pipe/Supercomputer - IBM 386-Compatible Computer - 2 Monitors	- Proprietary Software
Sigru	- IBM 486 Compatible - 3 - IBM 386-Compatible Computer - 2 Matrix Video Cards - 4 Monitors	- Proprietary Software
Titan	- IBM 486-Compatible Computer - Frame Grapher - 1 Monitor	- Proprietary Software
Traffic Tracker	- IBM 286-Compatible Computer - Video Card - Proprietary Cards -1 Monitor	- Proprietary Software
Tulip	- IBM-AT-Compatible Computer - Image Processing Card - 1 Monitor	- Proprietary Software

The video image processing equipment was evaluated using 20-minute segments of traffic images taped in S-VHS format. Different 20-minute segments were used to simulate varying weather, traffic, and installation conditions. Many of these tests evaluate system performance under less than ideal camera placement conditions. In total, 28 tests were performed.

In order to evaluate the performance of the equipment when installed according to the manufacturer recommendations, a representative sample was selected for which only traffic and weather parameters were varied. For these tests, camera placement can be considered optimal. The test results were summarized according to various categories such as time of day, camera placement, and direction of traffic. The following general observations resulted:

+ Accuracy of the better performing systems during daylight hours is comparable to the accuracy of inductive loop detectors.

+ System performance degrades significantly during transition and night-time hours, from reflections on wet pavement, and from shadows caused by traffic outside of the detection area.

+ Rainy night conditions cause the greatest inaccuracy.

The results of the CalPoly study indicate that the three commercially available systems (Autoscope, CCATS, and TAS) outperform the prototype VVDS equipment. The *Autoscope* and TAS systems provide the most accurate traffic volume count. The CCATS system is the most accurate for speed measurement. The Autoscope system is only slightly less accurate than the CCATS system. The CCATS system is prone to large errors in volume measurement during the transition and night-time periods. Based on tests conducted by CalPoly, Autoscope appears most promising. It should be noted that this technology is rapidly changing.

Closed-Circuit Television (CCTV) is traditionally accepted as an integral part of advanced traffic management systems. The opportunity to combine CCTV with vehicle detection by using video image processing techniques is highly advantageous for existing CCTV infrastructures and technology development. However, the need for the cameras to remain fixed conflicts with the need for pan/tilt CCTV functions. Accurate preset capability can alleviate this conflict. Other advantages of the VVDS follow:

+ Most VVDS system detector zones are not fixed. Detectors may be placed, modified, and relocated as appropriate.

+ No detector installation is required. The detector installation itself is in no way contingent upon pavement deterioration.

+ By tracking vehicle movements, VVDS can count turning movements and provide link travel times accurately.

The major disadvantage of VVDS is that the system is highly dependent on image quality and lighting. The total system costs are uncertain. VVDS is a relatively new technology with a very limited track record.

Another machine vision technology called Video Image Analysis (VIA) uses a computer to analyze video images received by television cameras placed along the roadway. A “mask’ frames the significant part of the image, typically a three- or four-lane roadway and emergency shoulder. The computer processes five pictures per second, compares them two at a time, and analyzes them for points that have moved between two successive pictures. These points are treated as objects moving along the roadway. If a moving object remains stopped within the mask for over 15 seconds, the computer considers this an anomaly and sets off an alarm.

Current implementations have experienced problems due to certain ambient light conditions. Adjacent structures which cast strong shadows can lead to false stationary traffic detections. Similarly, the auto-iris may put the system out of tune; rapid contrast changes may change the image content faster than the update rate. Methods to eliminate these conditions are under investigation. Recommendations based on operational test results include:

+ Using camera angles which capture traffic as it moves away.
+ Using polarizing filters.
+ Cleaning camera lenses at regular intervals.
+ Minimizing roadway lighting when possible.

Deployment considerations such as installation, calibration, field data processing, communication, and maintenance are similar to those for VVDS and CCTV. VIA systems require a fairly extensive calibration process, but the emphasis with VIA systems is to compensate for the effects of lighting changes.

VIA systems performing scenic analysis have been applied to traffic incident detection only recently. To date, VIA systems are not widely deployed, and have only recently (within the last 2 years) completed operational testing. Hence, the immaturity of the technology, the “architecture” of the system, and the fact that such systems require extensive image processing capabilities, require that the video image (scene) analysis be performed at the traffic control center. Full-motion, real-time video must be transmitted from the cameras deployed in the field to the control center.

4.2.1.8 Closed-Circuit Television

CCTV allows the FTMS operator to confirm any incident detected automatically by the VDS. CCTV relies on cameras, usually fully mobile, mounted at critical interchanges and roadway sections. The camera mounts should be on top of 40 to 60 foot poles or on over-the-road structures, such as roadway and sign support structures. Roofs of high buildings can also be used for camera mounting. The cameras mounted on high poles have an advantage, because the field of view is usually unobstructed and includes both directions of the highway and often some side-street areas. A zoom ratio of 1 to 8 or 1 to 10 should be sufficient for a effective range of 1 to 1.5 miles. Zoom ratios higher than 1 to 10 generally require a more stable pole to reduce sway. The camera mount must have full pan and tilt abilities and a zoom function. Solid-state Charge Coupled Device (CCD) technology has advanced in recent years, improving performance for traffic management applications.

As operation and maintenance costs increase, and as the need to distribute video information to other agencies becomes more prominent, there is an increasing desire to improve the quality of the CCTV system while reducing its operating costs.

The primary functions of the CCTV are incident confirmation and detection, flow monitoring, and verification of subsystem operation. To an increasing degree, the value of monitoring overall flow conditions by using overview camera placement is being recognized.

Presently, viewing distances realized with the existing camera technology exceed 600 meters for daytime conditions. The viewing distance is diminished to approximately one half of this value under inclement weather conditions, and water on the housing face plate further hampers visibility. Night-time visibility is typically diminished, though night-time video images are improved in areas of high-mast illumination.

Installation and calibration requirements include initial and periodic calibrations of the camera's pan/tilt position. Typically, three predetermined camera positions are provided as input to the camera controller. Regularly scheduled maintenance of the camera lens and pan, tilt, and zoom servers is required. These maintenance requirements must be considered when determining operational cost.

The communication requirements for CCTV systems depends on the particular functional and installation requirements of the traffic management center. For example, if a 1 to 1 camera-to-monitor ratio is desired for the TMC, it will be necessary to transmit all video simultaneously back to the TMC to a central video switch.

National Television Standards Committee (NTSC) standard CCTV cameras output a 1 -volt peak-to-peak 75-ohm signal which requires a minimum of 4.2 MHz, nominally 6 MHz, of bandwidth for full-motion analog video, as specified by NTSC standards. An Electronics Industry Association (EIA) standard applies to the transmission performance characteristics of transmission systems carrying 525-line NTSC television signals intended for broadcast or high-quality application.

Using these standards as a guide, a channel size of 6 MHz will be used to estimate the required analog capacity for the CCTV system as follows:

X CCTV x 1 channel = X 6-MHz video channels

Full-motion digital video requires a bandwidth of 45 Mbps to 192 Mbps, depending on the desired resolution. To include video within a standard digital transmission system, such as Synchronous Optical Network (SONET), each video channel will require a 45-Mbps data slot. Therefore, the required capacity for a standard digital video system would be:

X CCTV x 45 Mbps

Proprietary digital video systems use 192 Mbps for each full-motion video channel, requiring a capacity of:

X CCTV x 192 Mbps

Each camera will require a control signal for camera functions such as pan, tilt, and zoom. This control signal, ranging from 300 bps to 9600 bps full duplex, is usually transmitted over a common channel in a multidropped environment. The channel should occupy a 64-kbps data channel, the standard unit for channel assignment in the telephone industry.

A representative sample of camera manufacturer/supplier specifications and product information were researched. The following paragraphs describe the camera technologies relevant to CCTV.

Tube Cameras

Tube cameras employ an optical tube as the imaging device. Various tube technologies exist. The principal tube technology types follow:

+ Silicon Intensified Target.
+ Intensified Silicon Intensified Target.
+ Newvicon.
+ Ultricon.
+ Vidicon.

These camera types differ in the face plate material which serves as the optical receiver. All tube cameras produce a comparable high-resolution monochrome image with minimal scene illumination requirements. Typically, night images are characterized by blooming effects and image burn-in associated with intense light sources such as vehicle headlights. All of the tube technology cameras are susceptible to significant image degradation over time from limitations in tube life.

Camera manufacturers are discontinuing production of the majority of tube camera models. This trend can be expected to continue as development of solid-state CCD cameras continues.

Solid-State Cameras

Solid-state cameras use solid-state CCDs as imaging devices. Recent technological advances have enabled this technology to compete with the previously dominant tube-type cameras. While the CCDs low light sensitivity and resolution specifications do not compare favorably with tube imager counterparts, CCD imager capabilities are suitable for the freeway monitoring environment. CCD technology offers solid-state durability, color capability, and reduced blooming and burn-in characteristics.

Monochrome and color CCD cameras use three types of imaging system:

- X - Y addressed arrays.
- Frame transfer arrays.
- Interline transfer arrays.

X - Y addressed arrays use Metal Oxide Semiconductor (MOS) Capacitor pairs to store photo-generated charges. This type of system is typically used in machine vision applications and has lower resolution when compared to other systems.

Frame transfer systems move generated charge patterns from an imaging section to a storage section on the same silicon chip. A line-by-line readout from the storage section is performed by the register while the next field of photo-generated charges is being collected. The frame transfer system is analogous to serial processing.

Interline transfer systems move photo-generated charges from the image sensors along shielded storage columns spaced between vertical image sensors, to a register which reads out signals at TV-line frequency. The Interline system is analogous to parallel processing.

Intensified CCD cameras are also available. These cameras couple one of the previously described CCD systems with an optical tube to intensify low light-level images. Intensified CCD cameras are susceptible to the drawbacks associated with optical tube cameras.

All major manufacturers of CCTV equipment had CCD camera models available. Potentially suitable models and specifications are summarized in Table 4-5.

Table 4-5. Available CCD Cameras

Make	Model	Imager Type	Imager Size	Minimum Required Illumination	Horizontal Resolution	Minimum S/N Ratio
Burle	TC251	Interline	1/2"	3 lux @ F1.4	330 TVL	44 dB
Cohu	8200	Interline	1/2"	10 lux @ F1.4*	460 TVL	45 dB
Hitachi	VK-C240	Interline	1/2"	5 lux @ F1.4	320 TVL	46 dB
Ikegami	ICD-840	Interline	1/2"	5 lux @ F1.4	460 TVL	45 dB
Javelin	JE-3542	Interline	1/2"	3 lux @ F1.4	320 TVL	46 dB
JVC	TK895U	Interline	1/2"	10 lux @ F1.4	330 TVL	45 dB
Panasonic	WV-CL304	Interline	1/2"	10 lux @ F1.4	330 TVL	46 dB
Sony	SSC-C374	Interline	1/2"	2.5 lux @ F1.2	470 TVL	48 dB

* Value approximate - calculated from given face plate illumination.

Advances in camera technology and internal processing capabilities have enabled a digital zoom to be built into some Panasonic models. This zoom capability operates separately from and in addition to the optical zoom provided by the lens. The image is digitized, processed, and magnified by a given factor.

On a given video image, there are a limited number of pixels or picture elements which contain all of the information available from that image. As the picture is magnified, the image will appear grainy. Only a portion of the original image, not containing the entire screen set of display elements, is used to generate a full image. This lack of detail, or graininess, increases as the magnification is increased. For this reason, digital zoom will serve, not as a replacement for, but rather as a limited complement to conventional optical zoom. The majority of manufacturers had not incorporated digital zoom into their cameras: but as digital zoom it may be useful, its progress should be monitored.

4.2.1.9 Vehicle Probes

Vehicle probes offer real-time traffic information for a section of roadway, not the “localized” data offered by point detection devices. Real-time traffic and travel time information are available from vehicle probes employing Automated Vehicle Identification (AVI) or Automated Vehicle Location (AVL) systems. Each of these surveillance technologies is discussed in the following paragraphs.

<u>Automated Vehicle Identification</u>

Applications of AVI equipment include Electronic Toll and Traffic Management (ETTM) functions and electronic commercial vehicle clearance operations. Vehicles are identified using signals emitted from an onboard transponder and recorded by a roadside reader. The ability to identify a particular vehicle allows link travel times, average highway operating speeds, and vehicle entry and exit locations (i.e., the origin and destination within the network) to be computed for specific roadway segments. In areas where electronic toll collection is not available, “passive” or ‘non-cooperative” identification of vehicles may be performed using automatic license plate readers located at predetermined locations along the roadway. The travel time of the identified vehicle is used to calculate the average highway operating speed.

With the increasing use of AVI equipment for electronic toll collection in the Corridor, vehicle probe data may be acquired more easily and with minimal investment. This is a primary advantage of collecting available AVI information for traffic surveillance. Another advantage is the ability to estimate traffic origins and destinations within the network. Since the effectiveness of this surveillance technique depends on the participation level of the road users, its disadvantage is in the effort to attain a sufficient level of participation. Furthermore, from the perspective of a Corridor-wide surveillance system, AVI equipment standards must be adopted to allow AVI probe data to be acquired from and exchanged between different jurisdictions. Fortunately, the effort to standardize electronic toll collection equipment is being conducted by many agencies in the Corridor using the E-Z Pass system.

<u>Automated Vehicle Location</u>

AVL systems are computer-based vehicle tracking systems used to monitor the movement of transit and trucking fleet vehicles in realtime. They are beginning to be used to monitor police cars, ambulances, and other emergency vehicles. To facilitate vehicle tracking, the location of the vehicle is continuously reported to a central location for processing (refer to Figure 4-l). This information can be used to derive the average vehicle running speed. Furthermore, the drivers of such AVL vehicles usually can communicate with the central facility (e.g., a dispatching center) by means of voice and/or data communication and can report traffic incidents as necessary. The incident report can be automatically "stamped" by time and location, thus enhancing the effectiveness of incident detection and response.

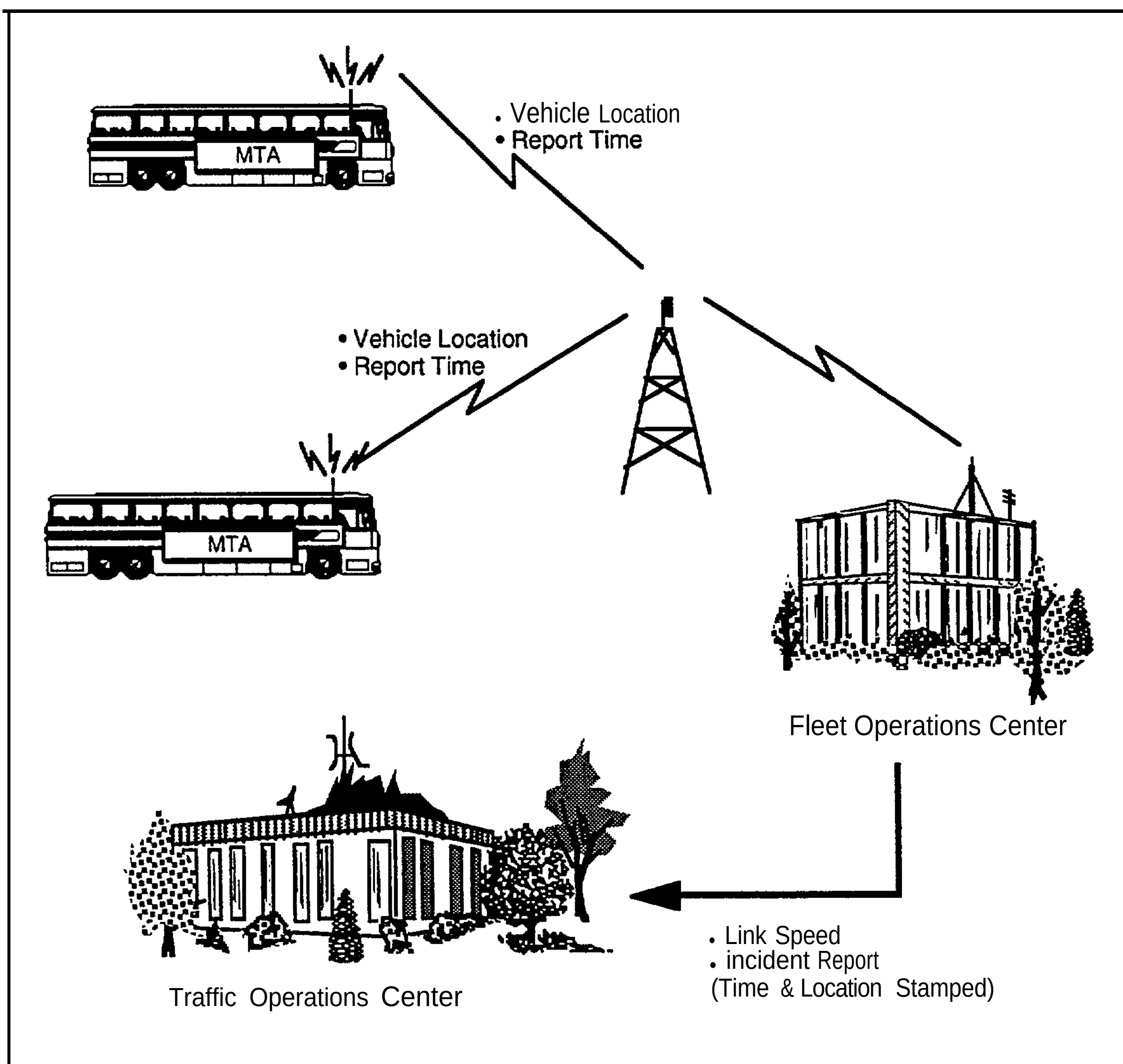


Figure 4-1. AVL Systems Can Supply Traffic Flow Information and Accurately Report Incident Location and Time

There are several types of AVL system currently in use [Federal Transit Administration, January 1994], including:

+ Signpost/Odometer.
+ Radio Navigation/Location.
+ Dead Reckoning.

Signpost/odometer systems are the most common form of AVL for transit vehicle tracking and include a series of beacons along bus routes. The beacons are normally mounted on utility poles and send out a low-powered signal which can be detected by an onboard receiver. Each signpost has a location identification which is relayed to the dispatch center by the passing vehicle. The location of the vehicle between two signposts is determined using the odometer that measures wheel rotation.

This signpost/odometer technology has been tested and used by transit systems for a number of years. Signpost/odometer use has not been widespread, however, because of the inherent inflexibility to relocate signposts when bus routes are changed, and the need to install a large number of signposts when the service area increases. In addition, this technology requires high levels of maintenance.

Radio navigation/location systems consists of ground-based and space-based systems. A well-known ground-based radio navigation system is Long Range Aid to Navigation-C (LORAN-C) which uses low-frequency radio waves to provide signal coverage. The vehicle's location is determined based on reception of the LORAN-C signals and the associated timing. The performance of an AVL system using LORAN-C is susceptible to RF and electromagnetic interference, which could result in errors as large as 1,000 m (3280 ft). In urban areas, the ability of an AVL system to receive LORAN-C signals is hampered by buildings and other structures (known as "urban canyons"). Because of these drawbacks, LORAN-C is no longer widely used [e.g., the Maryland Mass Transit Association (MTA) bus system is replacing its LORAN-C AVL system with the Global Positioning System (GPS)].

Another form of radio location system using radio frequencies in the 900 MHz band is provided by PacTel Teletrac services (which is now AirTouch Teletrac) [Federal Transit Administration, January

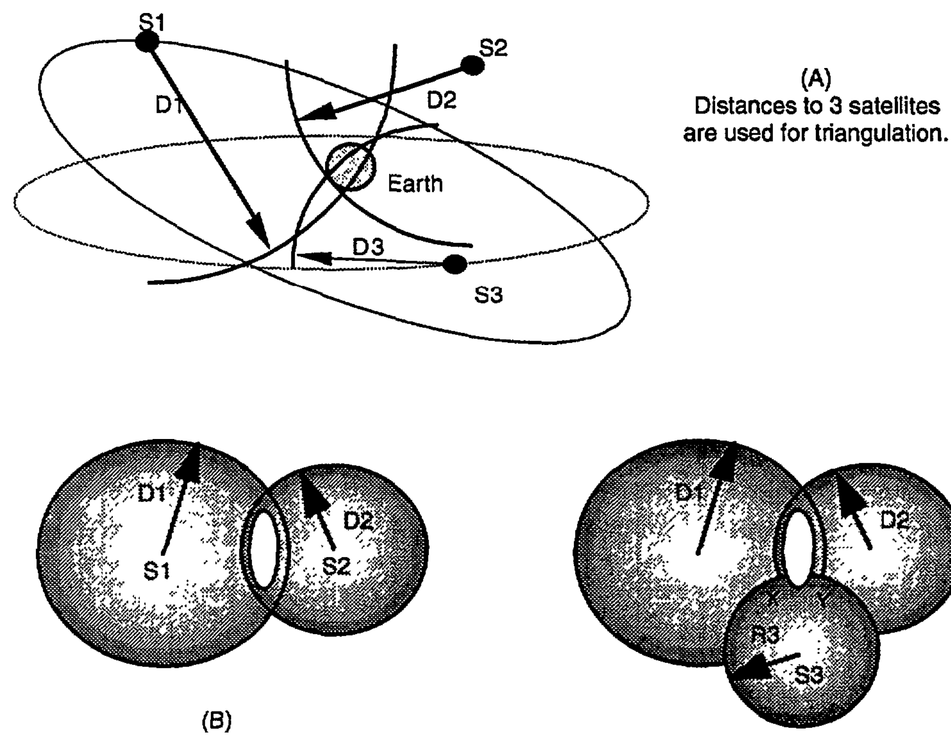
1994]. The Teletrac system includes a series of simulcast, high-power paging transmitters and specialized receiver sites located at strategic sites throughout the coverage area. The tracked vehicle is equipped with a radio transmitter. The transmitter's signals are triangulated at the receiving towers for position determination. Vehicle location data is then relayed to the subscriber's fleet control center. The system is able to locate a vehicle within 150 feet, and in some cases within 50 feet, depending on the terrain and "urban canyon" characteristics of the service area.

The Teletrac system has been used in Los Angeles, Chicago, Detroit, Dallas/Ft. Worth, Houston, and Miami. Its applications in Los Angeles, for example, include tracking package delivery, ambulance, sanitation service, and transit vehicles [Federal Transit Administration, January 1994]. It has also been used by the California Highway Patrol to track tow trucks that support the Los Angeles County Freeway Service Patrol (FSP). The performance of the Teletrac system in the FSP effort might not have been satisfactory (probably due to substantial delay in providing vehicle location data to the dispatchers or high operating cost). The system was later replaced with a GPS-based vehicle location system.

In recent years, an increasing number of AVL systems are moving toward the space-based GPS. GPS was developed by the U.S. Department of Defense as a worldwide navigation and positioning resource for both military and civilian use [Hurn, 1993]. GPS is based on a constellation of 24 satellites that transmit radio signals and act as reference points from which receivers on the ground can determine their position using triangulation (see Figure 4-2). The vehicle's location can be determined using three distance measurements from the receiver to the satellites. A fourth measurement is needed to correct errors resulting from any timing offset between the receiver and the satellites [Hurn, 1989].

The accuracy of "standard" GPS-based AVL systems is typically 50 m (164 ft) in the horizontal plane [Hurn, 1993]. This accuracy level can be significantly improved using Differential GPS (DGPS). Under DGPS [Hurn, 1989], a reference GPS receiver at a stationary (and known) location is used to determine all errors contained in the GPS data. These errors (including satellite clock, orbit accuracy, atmospheric delay, multipath, receiver clock, receiver noise, and intentional errors under "selective availability") are then used to compute a correction factor to be transmitted to other GPS receivers in the same locale. DGPS can produce submeter position accuracy.

As with any other radio navigation system, GPS signals may be masked or blocked by urban-area structures causing the vehicle track to be lost. To overcome these situations, dead-reckoning is usually employed in conjunction with GPS-based AVL systems. Dead-reckoning navigation can only provide temporary vehicle track data, because the errors associated with this technique can become significant after prolonged operation.



(B)
Two measurements define a circle containing receiver's location.

(C)
Three measurements defines two possible locations of the receiver in space (X or Y), one of which is unreasonable (away from earth).

Figure 4-2. Triangulation Concept for Position Determination Using GPS

The probe data from AVL systems can contribute significantly to the Corridor-wide surveillance system. The primary advantage of collecting AVL probe data is the minimal additional capital investment required to obtained traffic surveillance information. The majority of the investment has been made for vehicle fleet management purposes. The disadvantages, however, are:

+ There may not be a sufficient number of AVL-equipped vehicles traveling along the major Corridor highway network. Most AVL vehicles are buses that operated mainly on urban streets. Other vehicles, such as police and incident patrols, are not currently AVL equipped.

+ Institutional arrangements must be established to allow vehicle probe data to be generated from raw vehicle location data. These arrangements include processing and disseminating the data to agencies responsible for traffic surveillance, and protecting organizational privacy, such as identities of tracked vehicles (especially police). In addition, standardized geographic databases must be established to allow data transfer from one agency to another.

+ The lack of wireless communication media (e.g., radio frequencies) may hinder implementation of AVL systems for vehicle tracking. This has been a difficulty for many transit properties wishing to implement AVL systems.

4.2.1.10 Human Surveillance

This is the most common type of surveillance being performed. There are a number of human surveillance data sources, including:

+ Police patrols.

+ Freeway service patrols.

+ Motorists calling in using cellular phones or dedicated call boxes.

Human surveillance provides incident-related information and aids incident detection. During the existing systems survey conducted for this project (Chapter 3), many agencies in the Corridor reported using human surveillance for other purposes, such as gathering weather, environmental, traffic monitoring, and pavement condition information. The survey also indicated the general satisfaction of the I-95 Corridor Coalition members with the effectiveness of human surveillance.

Police and freeway service patrol surveillance techniques can be enhanced by using AVL systems to accurately locate surveillance assets and incidents, and to provide two-way communication between surveillance assets and the control centers. In Los Angeles County, the California Highway Patrol operates a Freeway Service Patrol program consisting of approximately

200 tow trucks (all under contract with private towing operators) during peak periods using Computer-Aided Dispatch and AVL (CAD/AVL) systems. The system detects and clears incidents effectively.

Implementing a cellular telephone motorist service requires installing interface equipment in the TMC. However, to encourage motorists to report traffic incidents, en route travel information dissemination assets (e.g., signs) would be needed. Thus, it is imperative that this service be highly marketed in order to maximize its potential.

Call boxes allow motorists to call for assistance in case of emergency. Today, most emergency phones are American Disabilities Act (ADA)-compliant and have built-in microphones and speakers. A person may speak without using a handset. Emergency phones are designed for different environments: outdoors, indoors, and environmentally hazardous areas. Many call boxes are designed to be vandal resistant.

Motorist call boxes require a substantial installation cost. Dedicated hardware support and telephone lines must be installed along the entire section of roadway. Call boxes should be logically placed to allow acceptable motorist walking times and infrastructure cost. Call box maintenance involves relocating phones when necessary, replacing dedicated pipes for telephone wire when needed, telephone repair, and scheduled system status checks.

The manpower required to operate the system at a control center, whether it is the TMC or another location, will have to increase to meet the increase incoming calls. Information from police and service patrols is considered reliable, but information from individual motorists must be confirmed before action is taken. This method of surveillance is useful in rural areas where the roadway vehicle detection system has long gaps between installations. Therefore, this method can be useful to the surveillance system.

Human surveillance includes the following advantages:

+ It can be used in areas, where vehicle detectors are not deployed.
+ It can provide incident detection, verification, and assessment information.
+ It can assist motorist in a timely manner and quickly remove minor incidents.

Disadvantages include:

+ It is man-power intensive, especially for large highway networks.
+ Timely detection of incidents depends on the number of personnel available.
+ It requires two-way communication to be effective.
+ It requires systems to monitor contractors' time and services, if contractors are used.

4.2.1.11 Aerial Surveillance

Aerial surveillance by helicopter and small airplane has been used by many police authorities and commercial radio stations to detect incidents and provide route advisory information to motorists on freeways and urban streets. In the 1960's, a study of the effectiveness of airborne-observer systems in rerouting traffic at incident sites [Weinberg, et *al,* 1966] indicated that the annual savings in motorist delay time could justify the use of such surveillance techniques. However, there was not conclusive evidence to show that aerial surveillance was economically feasible when compared with other methods of surveillance.

Efforts to improve the effectiveness of aerial surveillance have continued. In many metropolitan areas, traffic surveillance services with multiple aerial and ground observers have been organized (mostly by private traffic reporting organizations) to provide reliable services to multiple broadcast agencies. The effectiveness of such services greatly depends on the responsiveness of the broadcast media. However, the direct information they provide may be valuable to traffic management authorities, especially in today's traffic environment where 65 percent of urban freeway delay is due to non-recurring incidents.

One limitation of the early aerial surveillance systems was probably the lack of airborne surveillance equipment to extend the observation range. In the early 1970's, the use of CCTV inside of a helicopter was tested in Los Angeles [California Department of Public Works, 1973]. The results indicated that this system was not feasible, primarily because the response time of the helicopter to incidents was too slow for use in the motorist information system. Similar aerial surveillance systems are being tested in Montgomery County, Maryland and Fairfax County, Virginia.

Preliminary feedback from agencies testing these systems indicates that aerial surveillance can contribute significantly to incident management but not to incident detection.

Deficiencies of the current airborne traffic surveillance technologies may be overcome by advances in military airborne surveillance and control systems. Westinghouse Electric Corporation, in its defense technology conversion efforts, has developed a Multi-Sensor Surveillance Aircraft (MSSA) for air, maritime, and ground surveillance. The main features of the MSSA include:

+ Maximum take-off weight: 8,500 Ibs.
+ Usable fuel capacity: 2,000 Ibs.
+ Mission endurance: 7+ hours.
+ Maximum cruise speed: 170 knots.
+ Surveillance loiter speed: 90 to 100 knots.
+ Service ceiling: 25,000 feet.
+ Maximum range: 1,100 NMI.
+ Minimum crew: 1 pilot, 1 operator.
+ Maximum crew: 2 pilots, 2 operators.
+ AN/APG-66 SR radar with 360j rotating antenna.
+ WF-360 Forward-Looking Infrared (FLIR) imaging system.
+ Dual VHF and UHF radios, HF radio.
+ Ring laser gyro Inertial Navigation System and GPS receiver.
+ High-resolution multi-function display.
+ Radar/FLIR video recorder.
+ Real-time video data link.

Although the MSSA has not been tested for traffic surveillance and management purposes, it has been designed and tested for a multitude of non-defense applications, including law enforcement, drug interdictions, fisheries patrol, weapons range control, border surveillance, and forestry patrol. The estimated cost of the MSSA is between $6.5 million and $8 million, depending on the desired capabilities. Its estimated operating and maintenance cost (excluding personnel) is about $250 per hour of flight.

In addition to using aircraft for aerial surveillance, other platforms, such as airship and balloons, are emerging. The use of such vehicles is mainly to extend mission endurance. One such surveillance system, Aerostat Traffic Surveillance, is similar to the multi-sensor surveillance aircraft's but employs a stationary aerostat (tethered to a ground mooring) as the airborne platform. The aerostat carries an air-to-ground radar, an IR imaging system, and a TV camera. Because of the stationary nature of the aerostat, it may support ITS applications that require an area of continuous surveillance coverage.

The primary advantage of aerial traffic surveillance is the area-wide picture of traffic conditions along the roadways. Also, the mobility of an airplane allows it to reach an incident scene quickly enough to provide incident verification and assessment. Finally, with the availability of advanced wireless communication technologies, expensive terrestrial communication networks are not needed to transmit field surveillance data to stationary and mobile traffic management nodes.

The main disadvantages of aerial surveillance have been perceived as the system cost (capital, operating, and maintenance) and the limited area of coverage. However, there has not been any concrete evidence reported in the literature concerning the cost and benefits (especially in terms of traffic delay cost reduction) of advanced-technology aerial surveillance systems. Today's technology can substantially extend the surveillance zone of an airborne platform. The cost effectiveness of such systems should be reexamined. In addition, with the ITS market potential, private companies would be willing to provide aerial surveillance services to relieve their customers of the burden to operate and maintain the system. Another disadvantage is the inability of the platform to operate in adverse weather conditions during which service is needed most. Finally, sharing aerial surveillance assets (since conceivably they can serve multiple jurisdictions simultaneously) requires established institutional arrangements between agencies.

Another type of aerial surveillance platform is the Unmanned Aerial Vehicle (UAV). UAVs are small, unmanned aircraft remotely controlled by trained operators. These systems were developed by the Department of Defense for reconnaissance. UAVs are capable of carrying fully functional video surveillance equipment to provide real-time video data to a TMC. Today, there are a number of UAV manufacturers, including:

+ Freewing Aerial Robotics.
+ Westinghouse Electric Corporation.
+ Sikorsky Aircraft Division.
+ AAI/IAI.
+ Alliant.
+ Grumman/IAT.

One specific UAV is the Cypher being developed by Sikorsky Aircraft. The Cypher is a Vertical Take-Off and Landing (VTOL) system capable of hovering and maneuvering in confined areas. Originally designed for military surveillance applications, the Cypher has civil and commercial applications, such as hazardous waste site management, explosive ordinance disposal, and surveillance supporting police departments.

The main concern with UAVs for traffic surveillance is liability. Although these vehicles have been used extensively for military applications, commercially they are still in the experimental stages. Liability issues must be addressed. For traffic surveillance applications, these vehicles must fly over roadways to collect data. In such an operation, the concern is that accidents may occur if any technical malfunctions or failures cause the UAV to collide with overhead structures or into the roadway itself. This safety issue must be addressed and resolved when determining the suitability of the UAV for traffic surveillance.

4.2.2 Vehicle Weight Sensors

WIM sensors provide vehicle weight data important to pavement design and cost allocation. While accuracy of data is still important, average weight data are used to design pavement. Individual vehicle weights are not required. Absolute accuracy of sensor output is not necessary for pavement design, as long as the average data is within reasonable error limits. With recent advances in individual IVHS technology, automated toll collection is now dependent on determining individual vehicle weight accurately. Several IVHS tests are being conducted to evaluate weight sensors in conjunction with AVI. An evaluation study of WIM sensors has been undertaken by the FHWA and four I-95 Corridor Coalition members (Delaware, Pennsylvania, Maryland, and New Jersey). Under this project, a variety of sensors were installed in Delaware at the Pennsylvania State line. Results from this study, however, are not available at this time.

In this discussion of vehicle weigh sensing, two topics are presented: WIM technologies, and using multiple WIM sensors to improve the accuracy of weight measurements.

4.2.2.1 WIM Technologies

This subsection describes the operating principles of various WIM sensors. Table 4-6 summarizes the advantages and disadvantages of various sensors available at this time.

Table 4-6. Advantages and Disadvantages of Various WIM Sensors Identified through the Literature

Type of WIM Sensor	Advantages	Disadvantages
Bending Plate Systems	Relatively low installation cost.	Not portable
Shallow Weigh Scales	Relatively low installation cost.	Not oortable
Deep-pit Weigh Scales	• High accuracy (claimed) • Other vehicle measurements	• Not portable • Relatively high installation cost
Bridge Weighing System	Suitable to bridge structures	Low traffic applications only
Capacitive Systems	Portable and simple installation	Less accurate
Piezo-electric Sensors	• Operated without failure through a number of tests • Appears to be very durable	Operations depend on dynamic loads
Fiber-Optic Sensors	• Not susceptible to electromagnetic interference • Less expensive than piezo-electric sensors • Can be installed on the surface of the roadway, eliminating the need to dig the pavement • Less dependent on load frequency than piezo-electric sensor	Unknown

In general, WIM sensors are installed in or on the surface of the roadway with an accompanying roadside data collection unit. Regular calibration of the sensor and maintenance of the system are necessary. No field data processing is required. Specific roadway installation characteristics and operating temperature ranges of commercially available WIM systems will be discussed under each technology listed.

Bendina Plate Systems

Bending Plate WIM systems were developed and patented in Germany by the Bundesanstalt fuer Strassenweisen (BAST) [Davies and Ayland, 1985]. The system uses high-strength steel plate recessed into a shallow pit for high-speed dynamic weighing. The steel plates are used across a traffic lane, normally covering both wheel tracks. A light-weight frame supports the plates in the pit. The weighplate transducer is supported along its longer sides. Bending of the plate, as a vehicle crosses it, is measured by strain gauges located under the surface. This installation cost is low, considering the requirement of a 2-inch deep pit.

The bending plate system provided by the PAT Equipment Corporation operates at vehicle speeds of 2.5 mph to 70 mph with moderate accuracy levels (i.e., a random error of 8 percent for axle loads) [Sebaali, 1991]. The operational temperature ranges for the sensors and the roadside data collection unit are -40^{o} F to 175^{o} F, and -40^{o} F to 140^{o} F, respectively. This is designed as a permanently installed sensor.

Shallow Weigh Scales

Shallow weigh scale sensors consist of a steel frame supporting the load sensors and six triangular load plates [Davies and Ayland, 1985]. One of these transducers is installed in each wheel path. Each transducer contains eight effective load cells and eight matching load cells for correcting temperature effects. The depth of the pit is usually less than 4 inches, resulting in relatively low installation cost.

Deep-pit Weigh Scales

Deep-pit weigh scale systems are also known as Hydraulic Load Cell WIM systems. This type of system consists of two rectangular weighing platforms (one under each wheel track) resting on a common concrete foundation [Davies and Ayland, 1985]. Loads applied to a platform produce vertical movement in a centrally located oil-filled piston, which acts as a load cell. Inductive loops and roadside monitoring systems allow a range of vehicle parameters to be measured. High statistical accuracy is claimed for an all-in system.

The WIM system provided by International Road Dynamics (IRD) operates at vehicle speeds of 2.5 mph to 70 mph with accuracy levels similar to the PAT WIM system [Sebaali, 1991]. The operational temperature range for the weight sensors is -50^o F to 140^o F.

Bridge Weighing System

The bridge weighing system was first developed at Case Western Reserve University in Ohio [Davies and Ayland, 1985]. It uses reusable strain transducers clamped to the underside of the support beams of a highway bridge. Tape switches are placed on the road surface for the measurement of vehicle speeds. An optional manual input is also possible for detailed vehicle classification via a portable control box. The bridge weighing system is restricted to sites with light traffic and appropriate highway bridges and, therefore, may not be totally suitable for a statistically-based sampling strategy.

Another form of bridge weighing system, named CULWAY has been developed in Australia [Thillainath and Hood, 1990]. The CULWAY WIM system was originally conceived and tested in Western Australia by the Main Roads Department, and further developed by the Australian Road Research Board (ARRB). The CULWAY system uses axle sensors and a set of Mechanical Strain Amplifiers (MSA), affixed to the culvert unit beneath the road, to weigh and classify vehicles.

Capacitive Svstems

Capacitive sensors, normally in the form of weights fixed to the road, include two or more parallel steel plates separated by a dielectric material and encased in rubber [Davies and Ayland, 1985]. As a wheel passes over the sensor, the top plates deflect and cause a change in capacitance. This change is related to the axle weight passing over the sensor and is converted to a digital signal output by the system electronics.

The Golden River Capacitive Pad WIM Device (GRWIMD) is designed for portable applications, unlike the PAT and IRD WIM systems. However, GRWIMD is less accurate. The operational temperature range for the weight sensors is 32^0 F to 175^0 F. The temperature range for the roadside data collection unit is -40° F to 175° F. The GRWIMD operates at vehicle speeds of 20 to **70** mph with low accuracy levels (i.e., a random error of 12 percent for axle loads) [Sebaali, 1991].

Piezo-electric Axle Load Sensors

Piezo-electric sensors utilize a physical phenomenon called "piezo-electricity" [Davies and Ayland, 1985]. When a force is applied to certain parallel faces of some crystalline materials, electrical charges of opposite polarity appear at the parallel faces. This concept led to the development of piezo-electric WIM sensors using piezo-electric cables. The magnitude of the piezo-effect depends on the direction of the force with respect to the axes of the crystal. The piezo effect is dynamic, in that a charge is generated only when the forces are changing. Should a constant force be applied, the initial charge will decay. Most of the'piezo-electric installations use the round piezo cable. Other forms of piezo cable are also developed. The concept has been extended for the development of a piezo film, which uses a piezo material sandwiched between flexible rubber. Research has been conducted to develop a piezo film sensor for both permanent and portable applications. Cunigan and others (1991) developed a WIM system using piezo-electric film.

In 1987, the Washington State DOT completed the test of a French piezo-electric WIM system, developed by the French National Laboratory [ASHTD, 1992]. The system did not perform well enough to be used for traffic data collection for the Heavy Vehicle Electronic License Plate (HELP) Project.

Tests were conducted in Iowa and Minnesota using piezo-electric WIM systems provided by GK Instruments, Limited from the UK. The tests indicated that the traffic weight and classification data were comparable with other available low-cost systems for Portland cement concrete pavements. However, sensors on asphalt pavement did not achieve the accuracy equivalent to sensors in concrete pavement. Another test at Turner-Fairbanks Highway Research Center on GK Instruments provided inconclusive results.

Subsequently, GK piezo-electric WIM systems were installed in four different sites in Arkansas for evaluation. Tests showed that the device is capable of operating for extended periods of time under a variety of conditions without failure. The sensor allows relocation (removal and reinstallation) without destruction. The WIM systems performed similarly at all locations. The systematic difference, which is a measure of effectiveness of the operation of the sensor and the recorder, ranged between 0.37 percent and 3.2 percent at the four sites tested. The random difference, which is a measure of road and environmental impacts, varied from 13.37 percent to 19.75 percent.

<u>Fiber-Optic Sensors</u>

Fiber-optic technology, in addition to its principle application of communication, has also been applied to the domain of weight sensing.

The operation of fiber-optic weight sensors is based on the principal that an external disturbance to a light beam will affect the properties of the fiber, and in turn, the transmission of the beam. The magnitude of change is directly related to the measure of the external disturbance. For WIM fiber-optic sensors, the external disturbance is the pressure generated by the weight of a vehicle. This pressure causes perturbations (such as bends, microbends, refractive index changes, induced anisotropy, and dimensional changes) that affect the transmission properties of the light propagating in the fiber. Geometric changes, such as bends and microbends, affect the intensity considerably; and perturbations in the refractive index bring about significant changes in the phase. Variations of the phase result in an elasto-optic effect and changes in the fiber dimensions.

Safaai-Jazi, et al (1990) has designed, manufactured and tested a fiber-optic WIM sensor for a project under the SHRP-IDEA program of the TRB. The system consists of a pneumatic tube, filled with an incompressible fluid and embedded in a rubber pad, and a diaphragm designed ‘to determine pressure based on displacement. Its claimed benefits include:

+ It is not susceptible to electromagnetic interference.

+ It is less expensive than a piezo-electric sensor.

+ It can be installed on the surface of the roadway, eliminating pavement digging.

+ It provides accurate measurements, because its responses to applied loads are linear.

In France, Alcatel has designed a fiber-optic WIM sensor based on an optical property called the elasto-optic effect [Teral, 1994]. In an ideal fiber with perfect rotational symmetry, any polarization state injected would propagate unchanged. However, in a practical single-mode fiber, structural defects and mechanical perturbations (induced anisotropy) break the circular symmetry of the fiber. (Anisotropy refers to characteristics of a material which exhibit different properties in different directions.) Thus, when a load is exerted on the fiber, the fundamental mode of light supported by a single-mode fiber is divided into two orthogonal polarized modes, each with a different refractive index. The difference between the refractive indices, or the fiber birefringence (the refraction of light in two slightly different directions to form two rays) is used to determine the magnitude of the load as described below.

Alcatel's fiber-optic sensor structure consists of a set of optoelectronics, a single-mode transmission fiber, the fiber-optic sensor itself, and a mirror. The fiber optic sensor consists of an uncoated, single-mode fiber squeezed between two metallic ribbons embedded in a fiberglass, U-shaped groove filled with elastomer. The single-mode transmission fiber connects the sensor to a set of optoelectronics consisting of a laser diode, a polarizer, and a coupler on the transmission end, and an analyzer and photodiode on the receiving end. The other end of the fiber-optic sensor is connected to a mirror.

After crossing the optical fiber polarizer, the laser diode is launched into the optical fiber coupler and the transmission single-mode fiber, respectively. The polarizer establishes the polarization angle of the light at 45 degrees relative to the two orthogonal polarization modes to yield equal optical power in each of the polarization modes. The two orthogonal polarization modes appear at the sensor input. The interference pattern is reflected by the mirror located at the end of the sensor, and is transmitted through the transmission fiber to the analyzer and photodiode connected to the third arm of the coupler. The double pass of the light through the sensor increases the sensitivity by a factor of two. The force from the weight of a tire applied to the sensor gives rise to an induced birefringence, causing a phase difference between these two modes. Since this phase difference is directly proportional to the load, the weight is determined.

The detected optical intensity looks like a succession of maxima and minima corresponding to the weight distribution on the sensor. With the Alcatel WIM sensor, a typical vehicle signature is characterized by a number of maxima and minima, which depend on the total weight and the distribution of the maxima/minima, which depends on the weight distribution. Thus, the number of maxima/minima are constant for a given weight. The distribution of the maxima/minima depend on the rate at which the weight is applied; the higher the rate, corresponding either to high tire pressure or high speed, the tighter the distribution. This signature can be divided in three parts as follows:

+ A first succession of maxima and minima corresponding to increasing load as the tire rolls on the sensor.
+ A continuous signal indicating that the tire is centered on the sensor.
+ A second succession of maxima and minima corresponding to decreasing load as the tire rolls of the sensor.

The main claimed features of the Alcatel WIM sensor are:

+ High and adjustable sensitivity (with a dynamic range extending from pedestrians to heavy trucks), high accuracy, and high reliability.
+ Digital information.
+ No requirement for electrical power along the roadway.
+ Lightning and electromagnetic immunity.
+ Ease of installation.

By mounting the sensor in the roadway at an angle relative to the direction of travel, better wheel discrimination may be obtained. The total vehicle (dynamic) weight is obtained by adding the individual tire weights. The system also can be used for measuring vehicle classification (by weight and axle count), tire pressure anomaly (relative to other tires and with knowledge of vehicle speed), road temperature, and vehicle damping anomaly.

Use of Multiple Weigh-in-Motion Sensors

The load applied by trucks on pavement varies instantaneously based on various factors, such as road roughness, truck speed, suspension type, tire pressure, etc. The instantaneous dynamic load fluctuates above and below the static weight, and the difference can be significant. The WIM system measurement represents a snapshot of the dynamic loading condition at a certain instant, and hence is not accurate. For the same reason, a WIM measurement can not be duplicated using the same truck and same conditions. Cebon and Winkler (1991) proposed and tested a multiple sensor weigh station approach in which a series of weight sensors measures vehicle weights and estimates the static axle load by using the average value. A 38-m weigh-mat consisting of 96 capacitive strip WIM sensors was used in the test. A total of 460 test runs were performed using six different articulated vehicles. The tests indicated substantial improvement in performance of the sensors. The tests suggested that a robust design of multiple sensors can be achieved by using three or more evenly spaced sensors. With a three-sensor WIM system, the weight measurements were possible with less than 6 percent RMS error. Precise measurement of vehicle weight is very important for I-95 Corridor applications, considering the requirement of determining the weight of individual vehicles for automated toll collection applications.

Mamlouk (1991) proposed a different approach of measurement of vehicle weights using multiple WIM sensors. Under this approach, a multi-sensor WIM device is used to capture the dynamic force distribution generated by the truck wheels rather than estimating the static weights by averaging the measurements. The author also suggested that the pavement design methodology should use dynamic weight spectrum rather than the static weights, because the pavement performance is affected by the dynamic loads rather than the static loads.

4.2.3 Environmental Sensors

In general, environmental sensors measure road surface and air quality conditions. Pavement surface temperatures and conditions are obtained from solid-state electronic devices installed in the roadway. Visibility sensors use either visible light or infrared light. Both types of visibility sensors use the forward scatter principle to measure the atmospheric extinction coefficient to determine visibility at the location of the sensor. Visibility sensors have a range from 25 feet to 1 mile. Air quality sensors measure the presence of various pollutants by analyzing the attenuation of specific frequencies of an infrared beam associated with the IR absorption characteristics of specific gases, such as carbon monoxide and carbon dioxide.

Environmental sensors typically require little maintenance and calibration. Usually, these units need to be initially calibrated for local atmospheric conditions upon installation. These sensors are integrated units, therefore data processing is performed internally. They can be configured to only initiate contact with the TMC during alarm conditions. This allows for the use of cellular phone links, resulting in a simple communication system requirement.

The use of environmental sensors for highway applications is relatively new. There are not adequate studies available on the evaluation of environmental sensors. However, there is an ongoing operational test (Idaho Storm Warning) which is evaluating the effectiveness of three commercially available environmental sensors, namely, SCAN, LIDAR, and HANDAR™. The operational test is described in a later subsection.

Road Surface Conditions

The SCAN system can determine the road surface condition [Kelley, 1994]. Pavement surface temperatures and conditions are obtained from solid-state electronic devices installed in the roadway. The 13-cm diameter sensor is installed in a 14-cm diameter hole, flushed with the pavement surface. This type of sensor can provide an array of information. With the recent advances of technology, additional information can also be retrieved. The possible road surface data output from a SCAN system are provided in Table 4-7.

Table 4-7. Road Surface Sensor Data

Deployed Capabilities	Additional Potential Capabilities
• Pavement temperature • Dry/wet (above 0°C)/wet (below 0°C)/icy conditions • Dew • Frost • Absorption • Relative amount of deicing chemical present	• Freezing point of water/chemical solution on the pavement surface • Depth of water • Percentage of ice present

Subsurface temperature data are also available, by installing probes directly below the pavement at a depth of 40 cm. These probes provide frost depth data.

Visibility

The SCAN, HANDAR™, and LIDAR systems all provide visibility sensing. Currently, the Idaho Storm Warning Operational Test is evaluating the performance of these systems for visibility. SCAN, supplied by Surface Systems, Inc., provides two visibility sensors: one uses visible light, and the other uses infrared light. Both visibility sensors use the forward scatter principle to measure the atmospheric extinction coefficient to determine visibility at the location of the sensor. Visibility sensors have a range of 25 feet to 1 mile.

The HANDAR™ visibility sensor is a point detection device that utilizes a forward scatter principle similar to the SCAN system. The vendor's catalog claims that the HANDAR™ visibility sensor can measure the atmospheric visibility from 0.17 miles to 18 miles with an accuracy of 15 percent. The sensor projects a pulsed beam of infrared light into a sample volume of air. Aerosols in the sample volume scatter the light, and the receiver head detects the light scattered forward 30" to 40" off of the beam axis. The amount of light scattered forward is proportional to the atmospheric extinction coefficient. The visibility range is calculated by the sensor's microprocessor by the following expression:

Visual Range = 3.0/Extinction Coefficient

The LIDAR system is a single visibility sensor, provided by Santa Fe Technologies, that uses the laser technology developed at Los Alamos National Laboratories. The LIDAR system has the capability to provide visibility measurements covering a larger area, when compared to SCAN or HANDAR™ systems.

Weather/Air Quality

The SCAN system can measure wind speed and direction, air temperature, dew point, relative humidity, and precipitation. Precipitation measurements consist of the type (drizzle, rain, or snow), the intensity, precipitation rate, and total accumulation.

HANDAR™ also manufactures sensors for estimating wind speed/direction, air quality, air temperature, dew point, humidity, etc.

4.3 R&D SURVEILLANCE TECHNOLOGIES

This section provides a brief review of R&D efforts in traffic surveillance technologies being conducted in the U.S. and abroad. The efforts in the U.S. include R&D projects and operational tests. Efforts abroad are a combination of both, depending on the available information.

4.3.1 R&D Projects in the U.S.

There are a number of ongoing ITS R&D efforts in the U.S., including federal programs, state initiatives and university research. This subsection provides an assessment of the technologies in those initiatives.

Traffic Flow Wide-Area Surveillance

Traffic Flow Wide-Area Surveillance (TFWAS) is an FHWA R&D effort to provide an initial assessment of promising technical approaches for wide-area surveillance systems. Existing surveillance is based on point or extended point surveillance techniques that monitor vehicles passing through a small, single projected area. The Oak Ridge National Laboratory is currently conducting research to design a surveillance system for TFWAS. This project is important for future ITS evolution in which traffic management will depend heavily on accurate sensor information on a wide-area basis. This concept, if proven promising, will be suitable for the I-95 Corridor-wide surveillance system.

The concept definition of a wide-area system has been based on the human approach to sense a subject [Allgood, et. al, No Date]. A human being performs the traffic monitoring function with a wide view rather than looking at a reference line. The process of human sensing is a hierarchical process. The concept definition of a TFWAS differentiates between perception and cognition, as shown in Figure 4-3. A high volume of noisy data generated by individual sensing elements flows into a human brain (or an intelligent machine). The process of perception extracts context-dependent appropriate information from the data stream. Multiple precepts are integrated into concepts. Cognition, or formation of concept, is the process by which a human being sees things as they are.

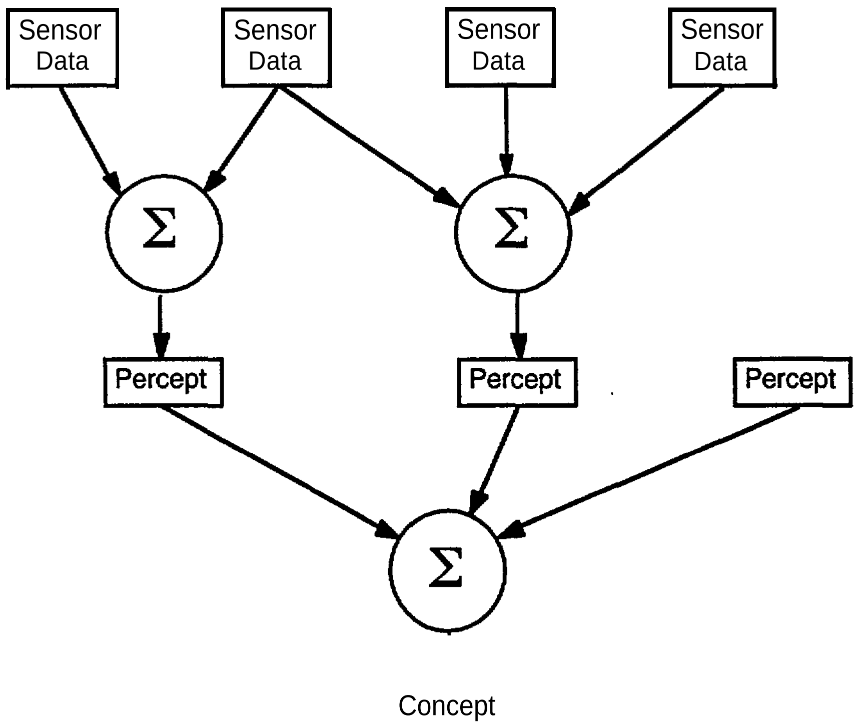


Figure 4-3. Hierarchical Process of Perception and Cognition

Ideally, a TFWAS performs a similar process of cognition. An array of smart sensors automatically converts data streams into a set of precepts, from which the system will determine the actual, consistent, overall traffic flow.

The design includes a dynamically reconfigurable sensor interface. Hardware should be provided to interface a variety of sensors to a general Input/Output (I/O) data bus in the TFWAS system. Software drivers should be provided for each interface, along with an interface engine that can determine what sensors are on the system. The design must be such that sensors can be conveniently plugged into and unplugged from the system.

Several currently evolving image processing applications go beyond point detection systems, are capable of analyzing the whole **camera view,** and can track individual vehicles. The design of a TFWAS system must consider that it will be implemented in the existing highway system in an evolutionary fashion. The preferred design should employ the existing point surveillance system to the fullest extent possible and be able to fuse data from existing and emerging sensor systems.

Wide-Area Land-Based Radar Sensor

The Low Cost Advanced Roadway Traffic Sensor (LCARTS) technology offers a larger surveillance coverage when compared with many existing point detection systems. It monitors traffic both upstream and downstream of its location and can cover distances of up to 3 miles in each direction. The output of this sensor includes the distribution of traffic density and traffic speed within the sensor's detection range. This output may be used to detect traffic congestion and to determine its location. The sensor is still being researched and developed. It should be available in the latter part of 1995.

The LCARTS is being developed by Mirage Systems in Sunnyvale, California. It is a wide-area, low frequency (10 MHz to 2000 MHz), low-power, continuous wave radar. It is capable of monitoring a 6-mile stretch of a multi-lane roadway, making it more attractive than other point detection systems. The LCARTS can be mounted on a pole on one side of the road (see Figure 4-4), avoiding traffic interruption during installation and maintenance. It monitors traffic in both flow directions and on both upstream and downstream sides of the sensor. The technical information described below was extracted from the literature provided by Mirage Systems.

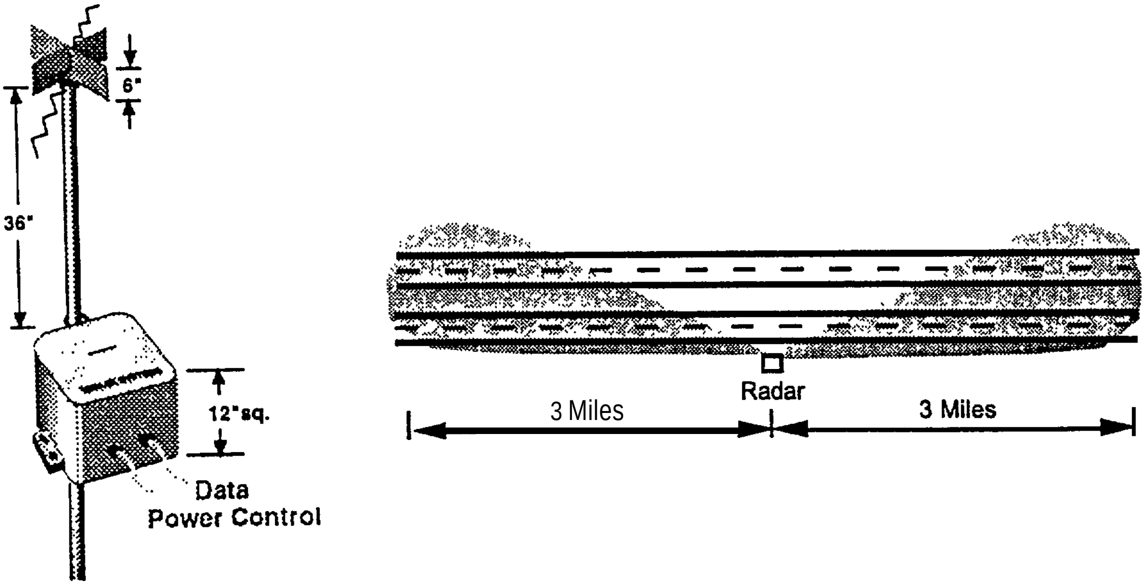


Figure 4-4. Features of the Low Cost Advanced Roadway Traffic Sensor

LCARTS design performance parameters being researched and developed include:

+ Range Coverage: Up to 3 miles in each upstream and downstream direction.
+ Minimum Detectable Traffic: One vehicle.
+ Average Speed Coverage: 3 to 100 mph.
+ Minimum Speed Range: 1 mph.
+ Minimum Update Time: Once per second.

The LCARTS can provide the following types of data for traffic surveillance:

+ Raw Traffic Flow Data: Traffic density versus range and speed.
+ Statistics of Raw Data (e.g., average values): Density versus range or speed; and speed versus range.
+ Incident Detection Data: Status and location.

The sensor data can be automatically processed to provide a three-dimensional display of traffic density (vehicles per range cell), range from sensor, and vehicle speed. Such a display is illustrated in Figure 4-5.

Laser-Based Vehicle Detector/Classifier

This IVHS-IDEA Project aims at transferring a defense technology to the field of transportation. Its purpose is to design and test a Vehicle Detector/Classifier (VDC) using laser imaging techniques to provide vehicle classification for application in automatic toll collection systems [Gustavson and Olson, 1994]. This technology was originally developed for submunition scanning laser guidance systems, and is expected to provide a highly accurate, three-dimensional profile of a vehicle at speeds of up to 100 mph.

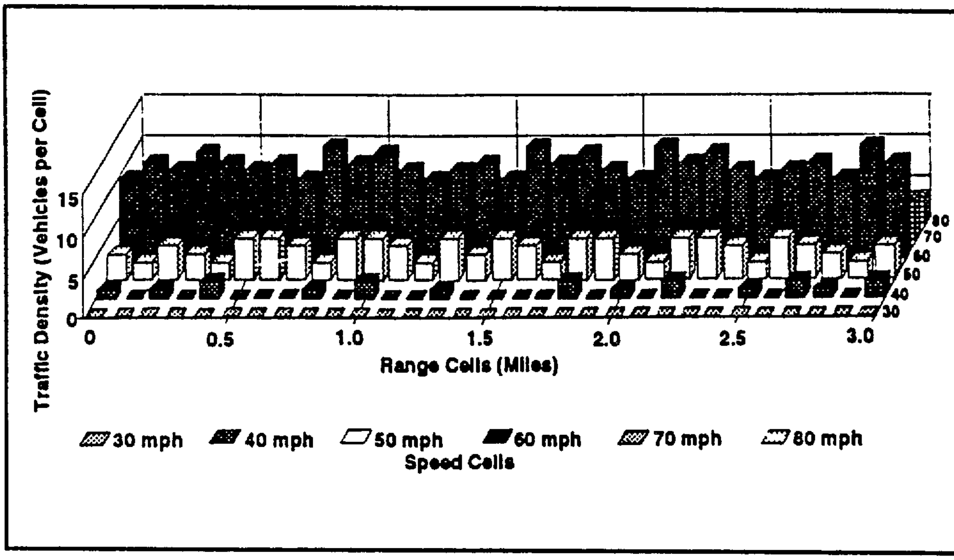


Figure 4-5. Three-Dimensional Display of Traffic Data Provided by the LCARTS

The VDC concept employs a scanning laser range finder to measure three-dimensional vehicle profile. The narrow laser beam width permits the detection of closely spaced vehicles moving at high speed. The VDC uses a rotating polygon to line scan a diode-laser range finder across a lane 12 feet wide. The range finder consists of a diode-laser transmitter and a silicon avalanche photodiode receiver in a side-by-side configuration. The transmitter consists of the diode laser, its driving circuit, and a lens. The optical receiver consists of a lens, a spectral filter, detectors/amplifiers, and a threshold detector. A block diagram of the VDC is provided in Figure 4-6.

The VDC design specification calls for a vehicle classification of 12 different classes and a speed accuracy of ± 2 mph at 60 mph. According to the research plan, a prototype system was to be fabricated and tested under highway operating conditions in March 1995. Thus, the test results were not available when this report was prepared. Although the VDC seems to have great potential for vehicle classification and speed measurement, it was not clear whether the VDC can extract other key traffic parameters, such as occupancy and queue-length information.

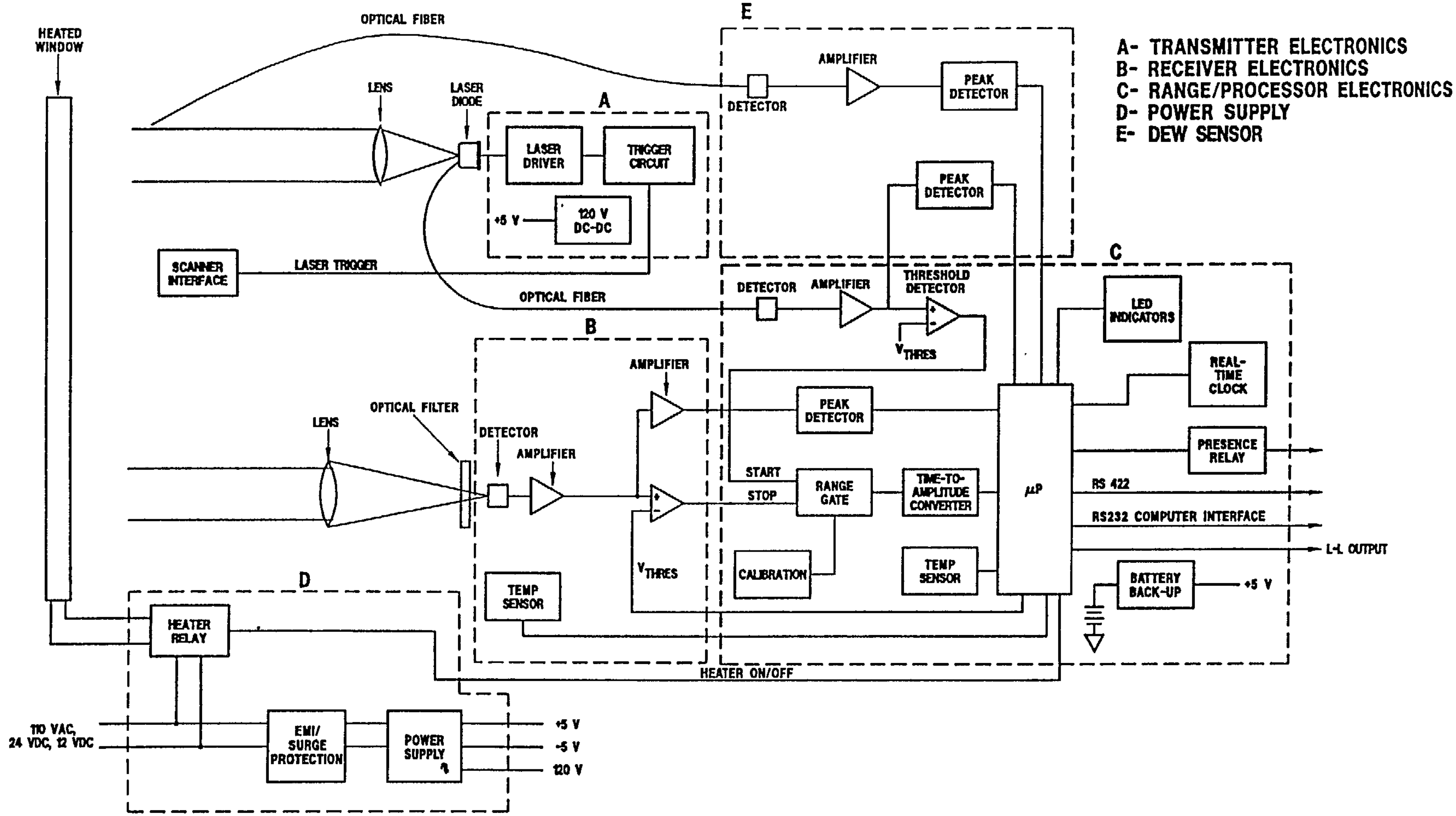


Figure 4-6. Vehicle Detector/Classifier Block Diagram
(Source: Gustavson and Olson, 1994)

AutoAlert: Automated Acoustic Detection of Traffic Incidents

This IVHS-IDEA project is another technology conversion project which uses military acoustic sensor technologies [Whitney, 1994]. The AutoAlert system monitors background traffic noise and compares it with the acoustic signatures of previously recorded accidents and incidents for detection. Figure 4-7 shows the concept of this system.

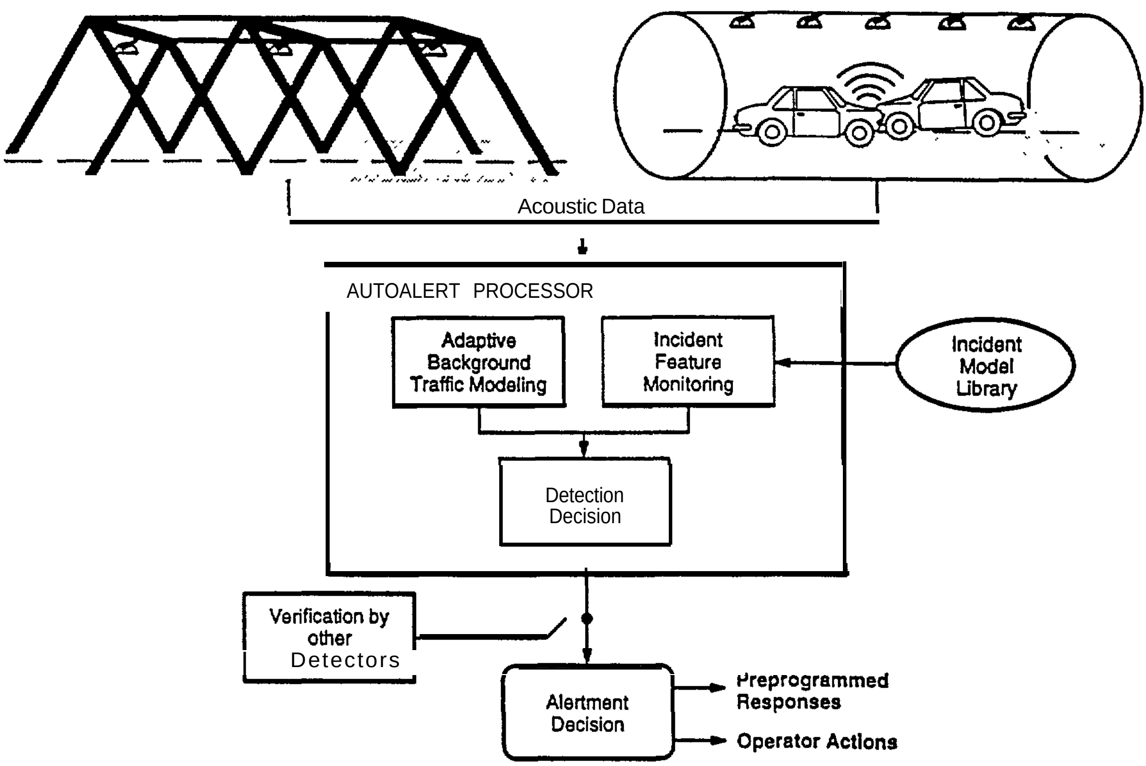


Figure 4-7. AutoAlert Concept Using Time-Varying Traffic Background Noise for Incident Detection

The AutoAlert System is expected to have the following performance capabilities:

+ Provide nearly immediate detection.
+ Provide low false alarm rates.

+ Offer reliable, all-weather, day or night detection under varying traffic conditions.

+ Identify incident acoustic signatures (e.g., “screech” and “crunch”).

+ Report a confidence level for detection.

However, no information was provided on the detection range of the sensor. If the range is short, numerous sensors will need to be installed in a series along a highway to detect an incident. In addition, it is unknown how effective this system would be in detecting other “silent” incidents, such as stalled vehicles on the roadway. Another potential shortcoming of this system is that the sensor provides only incident data, requiring other types vehicle detectors to monitor non-incident traffic flow conditions.

Since this effort was expected to be completed in April 1995, no further information was available at the time of this report.

<u>AVL for Measurement of Corridor Level of Service</u>

This is a field operational test conducted by the Center for Urban Transportation Research, University of South Florida (1994). The project was funded by the City of Miami for the evaluating the use of AVL to measure vehicle speeds on 17 transportation corridors. The operational test project started in April 1994 and ended in September 1994. The AirTouch Teletrac AVL system was used for this purpose. The AirTouch Teletrac system uses ground-based radio navigation and has been implemented in Los Angeles, Chicago, Detroit, Dallas/Ft. Worth, Houston, and Miami. The system provides location accuracy of 150 ft (50 ft in the Miami area because of the flat terrain).

The Teletrac radio-navigation system includes a series of simulcast, high-power paging transmitters and specialized receiver sites located at strategic sites throughout the coverage area. Vehicles to be tracked are equipped with Vehicle Location Units (VLU) that transmit radio signals.

AirTouch Teletrac maintains a network of 27 receiving antennas in the Dade, Broward, and Palm Beach counties of Florida. Signals from the VLUs are received by the receiving antennas and transmitted to Teletrac’s operations center in Ft. Lauderdale, where the vehicle locations are calculated and sent to the fleet operator workstation for display on a map.

In this field operational test, VLUs were installed on 25 vehicles for which data were collected over a period of time for over 4,400 vehicle trips. Software programs were developed to analyze the location data and calculate the speed specific to a trip and a certain road segment. Validation of the speed determination was conducted by manual collection of speed data. The result indicated that the observed data were within ± 2 mph of the calculated speeds.

The accuracy of the data appears to be very reasonable. The fact that this type of system utilizes already existing facilities makes the option very attractive. However, issues such as the timeliness of the data should be examined to ensure the operational effectiveness of the system.

4.3.2 Field Operational Tests

There are a number ongoing tests under the Federal Operational Test program. However, none of the tests have made enough progress to report any significant results. The purpose of this section is to briefly describe the concepts of the operational tests relevant to this Corridor-wide Surveillance System Study.

<u>"CAPITAL" Washington D.C. Area Operational Test</u>

This operational test is evaluating the use of the Bell Atlantic cellular telephone infrastructure with passive statistical cellular and cellular geolocation technologies to estimate traffic congestion and identify incidents [USDOT, 1994]. This test is particularly important to the I-95 Corridor project, because it involves a new concept using existing investments, and the test site is within the Corridor.

The demonstration area covers over 630 square miles of the D.C. metropolitan area, extending up to approximately 10 miles outside of the I-95/495 Capital Beltway. The second phase of the project will test the use of a packet data communication technique to transmit traffic information between the control center and commercial fleet vehicles. Traffic information will also be transmitted from the control center using the cellular data packets to office buildings, local cable companies, local television and radio stations, etc. Participants of the project include Bell Atlantic Mobile Systems, Engineering Research Associates (ERA), Farradyne Systems, Inc., the Maryland State Highway Administration, and the Virginia DOT.

This surveillance technique is very attractive, considering that it uses the available cellular communication infrastructure and does not require any in-vehicle device other than the cellular phone itself. The technique is similar to the Miami operational test which uses a ground-based navigation system for determining vehicle location. At the time of this report the test was being conducted.

Connecticut Freeway ATMS

This operational test (in Hartford, Connecticut) is evaluating radar detection technology in combination with CCTV for incident detection and verification [Mauritz and Stoeckert, 1994]. The test uses 44 radar detectors, some with a narrow beam, and others with a wide beam. The narrow beam detectors are designed to measure vehicle speeds in one lane of traffic only. They are installed at detector stations where the lanes of the highway have different uses (e.g., through lanes and exit lanes, or through lanes with HOV lanes). Wide beam detectors, which can be mounted on the side of the road, are used to monitor vehicle speeds in multiple lanes.

At each site, the individual radar detectors are connected to a nearby equipment cabinet. Inside of the cabinet, a multiplexer interfaces with each of the detector units installed at a detector location. The project also has two CCTV cameras to observe the traffic conditions within the study area. The cameras use CODEC technology to digitize the video image and send it to the Operations Center. All communications between the field equipment (detectors and cameras) are handled by leased telephone lines. The detector data is continuously sent to the Operations Center across dedicated data circuits at 1200 bps. The video cameras use T1 lines at 384 kbps.

The system uses four speed-based algorithms to detect incidents:

+ Mean speed.
+ Difference in speed.
+ Variation of difference in speed.
+ Standard deviation in speed.

These algorithms were developed to suit the surveillance data (mainly speed) generated by the traffic management system. An evaluation of speed measurements has indicated that the radars provide fairly acceptable estimates (refer to Table 4-8). However, the evaluation of volume accuracy indicated a large variation (10 to 60 percent), with the volume always under-reported by the radar. Apparently, the detector did not collect data during polling by the Multiplexer. This problem could be avoided with a "direct connect" configuration, where the detector is connected directly to a processor, and no polling is involved. Evaluation of the effectiveness of the speed-based incident detection algorithms is ongoing and cannot be assessed.

Table 4-8. Detector Accuracy for Speed Determination

Detector Type and Installation	Average Difference (in mph)
Narrow beam aimed toward approaching traffic	2.5
Narrow beam aimed toward departing traffic	2.6
Wide beam mounted over the roadway and aimed toward approaching traffic	4.1
Wide beam mounted over the roadway and aimed toward departing traffic	2.8
Wide beam mounted on the side of the roadway and aimed toward approaching traffic	4.5
Long -range detector mounted on the side of the roadway and aimed toward approaching traffic	10.0

Radar detection technology has potential for deployment within the I-95 Corridor. The technology offers the convenience of roadside or overhead implementation and provides reasonably accurate data. If the performance of the speed-based incident detection algorithms is acceptable, the radar detection technology may provide a combination of desired features (e.g., low cost, easy installation/relocation, relatively mature technology, and accurate data output). Furthermore, a general interest of the I-95 Corridor Coalition members toward future use of radar detection technology has been observed in the survey conducted for Task 1 of this Project.

Mobile Communication System

This project (in Orange County, California) will test and evaluate the use of a portable detection and surveillance system for highway construction, special events, and incident location [USDOT, 1994]. Twenty-one systems will be installed on special trailers which will be strategically placed at temporary traffic congestion locations in Orange County. The trailer-mounted video image detectors will use spread spectrum radio and/or Very Small Aperture Terminal (VSAT) satellite to transmit real-time data and video to provide a communication link with a control center located at the CalTrans district office. Participants of the project include CalTrans, Programs on Advanced Technology for Highways (PATH), the City of Anaheim and Irvine, CalPoly State University, and Hughes Aircraft.

The project is currently in the planning stage, and the trailer is being designed. Therefore, no results were available at this time. Depending on the outcome of the project, this technology will provide a means for the transportation agencies to set up ground-based mobile surveillance and control of non-recurring traffic problems, such as special events, construction, incidents, etc.

Smart Call Box

This project (in San Diego, California) will evaluate the use of the existing motorist aid call box system for other traffic management strategies [USDOT, 1994]. It is the intention of this operational test to convert the call box to a multifunctional IVHS system component. The test will evaluate the cost effectiveness of converting existing cellular-based call boxes to transmit the data necessary for traffic monitoring, incident detection, hazardous weather detection, changeable message sign control, and CCTV control. Participants of the project include CalTrans, the California Highway Patrol, SAFE, and several call box and detector suppliers. The project is underway, but no results are available yet.

The outcome of the project is significant to the I-95 Corridor. The technology makes use of existing investments and attempts to use them to the fullest extent possible. If proven effective, it can reduce the cost of future deployments of traffic and environmental sensors on the roadway, especially in rural areas where no communication mechanism is otherwise available.

Idaho Storm Warning System

This project (in Southeastern Idaho) will test three sensor systems to measure environmental conditions as they affect drivers at visibility-related multiple accident sites on I-84. SCAN, HANDAR™, and LIDAR systems will be used to measure visibility during blowing dust and snow situations [DOT, 1994; CH2M Hill, 1993]. Information will be automatically transmitted to two overhead signs to warn motorists. Participants of the project include the Idaho Transportation Department, CH2M - Hill, HANDAR™, and Santa Fe Technology, Inc.

Last year, the weather was not adverse enough for conducting the test, and the expected completion of this study has been delayed to spring 1996. No significant evaluation results have been obtained yet.

This particular operational test is important to the I-95 Corridor. To date, there has not been enough evaluation of weather-related sensor technologies for highway application, especially for traffic management during snowstorms.

Multi-Jurisdictional Live Aerial Video Surveillance System. I

This is a federal operational test project to procure, install, and evaluate live video transmission from a gyro-stabilized camera mounted on helicopters for observing, evaluating, and properly managing major highway incidents and situations of a public safety nature [USDOT, 1994]. This operational test is conducted in Fairfax County, Virginia and includes the FHWA, the Fairfax County Police, the Virginia DOT, and the Virginia State Police. Live color video is transmitted to police and state highway traffic management centers, and to mobile command centers at incident sites. Communication technologies include microwave, community access TV, and state-owned coaxial cables. The real-time, air-borne video was expected to be a valuable part of an ATMS, particularly in major incident management.

The evaluation was completed, and the final report was being prepared. The evaluation indicated that the use of helicopters for incident management was very effective. However, the use of helicopters for congestion monitoring and management was not very effective because of the long flight time needed for the helicopter to arrive at the congestion location.

Multi-Jurisdictional Live Aerial Video Surveillance System. II

This is another federal operational test with aerial surveillance [USDOT, 1994]. This is similar to the one in Virginia and is evaluating the live video transmission from fixed-wing aircraft (Cessna 206) to county and state traffic management centers in Montgomery County, Maryland. Test partners are the FHWA, the Montgomery County Office of Traffic, and the Maryland State Highway

Administration (MSHA). The components of the aerial surveillance system are shown in Table 4-9 [Donaldson, 1994].

Table 4-9. Components of Montgomery County Aerial Surveillance

Location	Components
Airplane	Microwave transmitter GPS receiver Color video camera Color video monitor S-VHS player/recorder Microwave antenna
TMC	Microwave receiver Automated tracking system Antenna control system Color video monitors S-VHS editing system
Portable ground system	<u>Transmit</u> Microwave transmitter Microwave antenna Color video camera Tripods Batteries <u>Receive</u> Microwave receiver Microwave antenna Color monitor S-VHS player/recorder Tripod

Preliminary testing indicates that the aerial surveillance system performs well as long as a good signal can be received. Video signals can be received form the airplane from any point in Montgomery County while it flies at an altitude of 1000 feet above the ground. There are certain areas in the county where other microwave signals are interfering with the signals from the airplane. This may be addressed by switching to another frequency. Tests of the portable receiver have been very successful.

It appears that both aerial surveillance operational tests compete to some extent with the mobile communication system operational test (discussed earlier). The difference is in the location. One is ground-based, and the other one is aerial. The aerial surveillance and mobile communication center has the advantage of responding quickly to a demand. The current air-borne surveillance systems use conventional sensing equipment, so efficiency can be increased further if automated techniques are used. For example, if an image processing technique is used for overhead signs to warn motorists. Participants of the project include the Idaho Transportation Department, CH2M - Hill, HANDAR™, and Santa Fe Technology, Inc.

Last year, the weather was not adverse enough for conducting the test, and the expected completion of this study has been delayed to spring 1996. No significant evaluation results have been obtained yet.

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Observation Balloon Svstem

Delaware DOT is evaluating an Observation Balloon System (OBS) for surveillance of its road networks. It is a low-cost, low-tech method of surveillance. This provides a birds-eye view of **a** highway for the purpose of incident detection, congestion management, and traffic monitoring. The evaluation is expected to be completed by late 1995.

A gyro-stabilized TV camera is suspended from a helium-filled balloon deployed from a fixed or a mobile station. A single cable provides the power supply and two-way communication, and anchors the balloon. The camera is controlled remotely from the ground. It can hover at a maximum height of 1,000 feet and provide a coverage area of 8 miles in diameter.

Like the previously discussed air-borne surveillance techniques, the OBS has potential for Corridor-wide application. However, the same recommendation is made here for using advanced image processing techniques, which could make the use of such systems more effective.

4.3.3 R&D Efforts Abroad

4.3.3.1 Canada

Canadian IVHS activities are carried out by both public and private organizations. The IVHS Roundtable of the Transportation Association of Canada acts as a monitor for these activities. Canada is also a participant in several North American operational field tests, including the Heavy Vehicle Electronic License Plate (HELP) Program, Advantage l-75, and the Wide-Area Vehicle Monitoring (WAVM) Project. Current Canadian programs include:

+ AVION (Vehicle Monitoring Automation).
+ COMPASS.
+ IVHS Roundtable.

- Municipal Traffic Information Production System (MTIPS).
- TravelGuide.

AVION

AVION is an Ontario Commercial Vehicle Operations (CVO) project that is being implemented in connection with the Advantage I-75 Program and the border crossings project at the Ontario/Michigan border. The objective of both the AVION and Advantage I-75 projects is to facilitate border pre-clearance, allowing non-stop travel across interstate borders and making the U.S. - Canada border crossing significantly more efficient. The project will use IVHS technologies such as AVI, Smart Card transponder, WIM, and electronic document processing to monitor and verify truck movements and compliance with regulations on Highway 401 between Detroit and Montreal.

As an extension to the Advantage I-75 operational test, the AVION demonstration program intends to use commercial vehicle transponders to acquire travel time information in heavily traveled urban roadways. The travel time information will be shared with other traffic management agencies through the MTIPS program described below.

COMPASS

COMPASS is a real-time Freeway Traffic Management System (FTMS) in Toronto focused on incident detection and response. CCTV and in-pavement sensors monitor traffic and relay the information to a central facility. This facility notifies the appropriate personnel of incidents and transmits information about traffic conditions to Changeable Message Signs (CMS). This program is sponsored by the Ministry of Transportation Ontario (MTO), and has been operational along the Queen Elizabeth Way for several years with technological upgrade assessments and operational field tests. The next phase to the project is to install integrated, compatible systems in Toronto and Ottawa.

The COMPASS program, as a relatively mature IVHS program, has three major areas of emphasis: ongoing operations for instrumented roadways; incorporating IVHS provisions in roadway expansion projects, expanding the instrumented roadways; and research and development initiatives. Research and development initiatives include the use of travel data from transponders associated with other IVHS projects, and the development of so-called “light infrastructure” IVHS, including demonstration tests of advanced vehicle detection technologies, advanced algorithms, and wireless data communication techniques.

In particular, the COMPASS program will make use of travel time data collected by other agencies and programs from transponder-equipped vehicles, including transit vehicles associated with the Toronto Transit Commission, commercial vehicles associated with the AVION program, taxis and limousines associated with Peason Airport, and private vehicles equipped with Electronic Toll Collection (ETC) transponders associated with the 407 ETTM development.

As part of a general trend to develop “light infrastructure” IVHS, the COMPASS program has been investigating the use of alternative vehicle detection technologies and techniques. These include the Remote Traffic Microwave Sensor (RTMS) operational test, which was conducted over a limited stretch of Highway 401 in Toronto. In this test, a number of microwave detectors were installed to investigate their utility as replacements for loops. The detector data was transmitted to the traffic management center over the commercial Mobitex digital (packetized) data network.

Though the original concept to use the sensors as loop emulators was found to be impractical for incident detection, the sensors are being deployed as an independent incident detection system to support the loop-based system. The RTMS data will be processed using single-station incident detection algorithms, instead of the standard multistation algorithms (e.g., the California algorithms) associated with loop detection data. Developments in the single-station algorithm incident detection algorithm approach are also in keeping with the emphasis to provide required functionality with lower capital cost.

The trend toward light infrastructure ATMS is driven by the fact that conventional IVHS expansion requires large capital outlay to deploy loop detector stations with sufficiently close spacing to provide effective incident detection, the deployment of CCTV equipment for incident verification and video vehicle detection, and the communication infrastructure costs for fiber-optic cabling and equipment. To cover new roadways in a less capital-intensive manner, alternative vehicle detection technologies, such as the RTMS system and other overhead (lower installation cost) detectors, are being deployed with spacings much greater than conventional loops. Using single-station algorithms complemented with travel time data from transponder-equipped vehicles, using cameras mounted at greater heights to provide incident verification coverage of greater sections of roadway, and using wireless communications technologies to avoid large communication infrastructure costs, equivalent surveillance and incident detection functionality is being achieved.

Municipal Traffic Information Production System

The Municipal Traffic Information Production System (MTIPS) is a real-time traffic information system which is planned to cover the entire metropolitan Toronto area. Participants include:

+ Ministry of Transportation Ontario.
+ Metropolitan Toronto Traffic Control Center.
+ Toronto Transit Commission.

MTIPS's first stage was a demonstration project tested in 1992. The goal of this project was to show MTIPS's ability to collect real-time traffic data and process it into a transmittable data stream for a 4-square mile area of metropolitan Toronto. Information from the city's Automatic Vehicle Location and Control (AVLC) system, which tracks city buses, the Toronto Traffic Commission (TTC), the Communication Information System (CIS), COMPASS, and a network of microwave sensors, loop detectors, video monitors, and computerized traffic signals, was all collected and processed at a central location. Historical traffic data patterns, real-time incidents, such as accident and static incidents (i.e., construction) were also included. The resulting information will be used for traffic management and route planning in applications such as the TravelGuide program. A fully operational data fusion system is planned within 5 years. The system will be operated by public/private partnerships. A suburban demonstration of this project is also planned.

4.3.3.2 Europe

In Europe, government and industry work together to fund research and develop IVHS services. It should be noted that IVHS is termed Road Transport Informatics (RTI) or Transport Telematics Applications (TTA) in Europe. European IVHS standards activities are being addressed by Technical Committee 278 of CEN, the European Standards Organization.

Although the majority of European IVHS programs concentrate on traveler information services and in-vehicle navigation, there are a few efforts related to surveillance systems and technologies as described below.

BEATRICS Sensors

Currently, THOMSON-CSF (Radar Division) in France has developed two versions of a radar for automatic incident detection and traffic analysis for highway traffic management [Lion, 1994]. This system is required to be capable of monitoring multi-lane roadways in both directions over a distance of 100 to 1000 meters. The system performs real-time incident detection and congestion detection. The BEATRICS radars are presently undergoing operational testing at two sites: a Societe des Autoroutes Paris-Rhin-Rhone (SAPRR) test site and the THOMSON-CSF factories.

These radar technologies have two operational versions:

+ Automatic Incident Detection Radar.
+ Traffic Analysis Radar.

The basic features of these two systems are identical. The radar has its own real-time processing which communicates through a digital network to the central computer via RS422 connections. The expected life of the sensors is 10 years with a Mean Time Between Failure designed for two years.

The Automatic Incident Detection Radar (AIDR) is mounted above the roadway, ideally in the central separation between each direction at a minimum height of 8 meters. The radar is able to monitor both directions of travel at a range of 100 to 1000 meters. The features of the AIDR include:

+ Detection of stopped vehicles in the main lanes and shoulder lanes.
+ Detection of congestion with indication of beginning and ending point and direction.
+ Measure the average, minimum, and maximum speed.

Specified performance for incident detection function and congestion detection function are:

+ Vehicle stop rate greater than 95 percent.
+ False alarm rate less than l/day in heavy traffic conditions.

The Traffic Analysis Radar is located on one side of the roadway at a minimum height of 8 meters. It is capable of monitoring 10 lanes and provides the following parameters for each lane in a given period of time:

+ Vehicle count data.
+ Average, minimum, and maximum speed.
+ Heavy Good Vehicle (Heavy Good Vehicle) percentage ratio.
+ Occupancy rate.
+ Headway.

Operational radar prototypes are available for customer performance evaluations which should continue through 1995. It should be noted that no actual operational data is available, and demonstration testing has not been completed. The specified performance rates for AIDR have not been confirmed. This system has not been employed in the field for operational testing. No statistical data is available at this time.

Automatic Incident Detection throuah Video Picture Analvsis

In 1992 the French Toll Motorway Companies Union initiated testing a new Automatic Incident Detection (AID) technique proposed by the French National Institute for Research on Transportation and Security (INRETS) [Daviet, et al, 1994]. The technique consists of utilizing computers to analyze video images received by television cameras placed along the roadway. A "mask' frames the significant part of the image, which typically is a three or four-lane roadway and the emergency shoulder. The computer processes five pictures a second, compares them two at a time, and analyzes them looking for points that have moved between two successive pictures.

These points are treated as objects moving along the roadway. If a moving object stops and remains stopped within the mask for over 15 seconds, the computer considers this an anomaly and sets off an alarm.

Several experiments have been conducted to analyze the validity of AID using this method. One experiment was performed on the ESCOTA Company network, on an urban section of the A8 motorway, west of Nice. Experimental equipment consisted of 6 CCD cameras furnished with polarizing filters, with focal distances varying form 130 to 470 meters.

Pictures from these cameras were sent back to a central processing center via fiber optic cable. Operators were able to compare real incidents versus "detected" incidents. The experiment lasted 46 days resulting in over a 90-percent detection rate, a 6-percent false alarm rate, a 22-second delay in detection, and 1 false alarm per camera once in 5 days.

Also in 1993, as part of the European MELYSSA project, the AREA Company conducted a full scale test over an urban section of the A43 motorway located east of Lyons. The roadway was equipped with 16 cameras on IO-meter masts or bridges with focal distances varying from 16 to 100 km, and fields of detection oscillating between 150 and 600 meters. The testing period lasted 3 months. Results indicated an AID rate of 86 percent with 4 false alarms per day for 16 cameras.

Another motorway company, COFIROUTE, installed eight cameras on the city crossing section at Tours. Initial results indicated a detection rate of greater than 90 percent, and a false alarm rate of 25 percent with a false alarm frequency of 0.8 per 24-hour period and camera.

Noting the differences in results from the first experiment and the operational testing, the USAP decided to conduct AID using picture analysis in tunnels where lighting conditions are unique. This experiment took place on the A8 motorway in Nice from November 1993 through February 1994. The results obtained were a detection rate between 87 percent and 90 percent, a false alarm rate of 0 percent, and a false alarm frequency of 0.25 (1false alarm per camera once every five days). The following recommendations were made based upon these results:

- Use camera angles which capture traffic as it moves away.
- Use polarizing filters.
- Clean camera lenses at regular intervals.
- Have minimum roadway lighting when possible.

Image Processing and Automatic Computer Traffic Surveillance

Image Processing and Automatic Computer Traffic Surveillance (IMPACTS) is a computer system for automatic traffic surveillance and incident detection using output from CCTV cameras [Hoose, 1994]. Recent developments have been made which advance CCTV system performance under adverse lighting conditions, reliability of incident alarms and user interfaces. A pilot system which is based on a modular design has been tested in London and a multi-camera system has been installed in Strathclyde.

The algorithm utilized by the IMPACTS system takes a different approach from most other image processing techniques that have been applied to traffic monitoring. Road space and how it is being utilized by traffic is considered instead of identifying individual vehicles. This leads to a qualitative description of how the road, within a CCTV image, is occupied in terms of regions of empty road or moving or stationary traffic.

The pilot system test used live camera data from images received at the East London Control Room, Blackwall, London. The objective of the trial was to provide data on the performance of IMPACTS over an extended period of time, and to compare these results with the output from a loop-based incident detection algorithm, HIOCC.

The results showed that the system can successfully detect queues of stationary traffic, stopped isolated vehicles and empty roads. A spatial occupancy measure gives a general indication of traffic density and hence traffic conditions. The system successfully detected the return to moving traffic once a queue was cleared. The one minute spatial occupancy value gave a strong indication of the current traffic conditions. The trial results showed that the system gives good performance for cameras mounted in tunnels away from the portal lighting. Alarm detection of better than 90 percent resulted. The false alarm frequency was low, approximately 1 every 24 hours, and the false alarm rate was approximately 0.07. The typical detection time was between 5 and 10 seconds.

Comparison with loop-based incident detection algorithm, HIOCC, is not completely clear. IMPACTS alarms are based on vehicles stopping while the HIOCC will react to slow moving traffic. In general HIOCC and IMPACTS alarms occur within the same time period. There are some complimentary aspects, such as the use of IMPACTS spatial occupancy to confirm correctness of the HIOCC alarm. Additionally, IMPACTS can report when traffic has come to a halt and detect isolated stationary vehicles. IMPACTS can also determine when traffic has started to move and when congestion has ceased.

Current implementations have experienced problems due to certain ambient light conditions. Adjacent structures which cast strong shadows can lead to false detection of stationary traffic. Similarly, rapid changes due to the functioning of the auto-iris can result in changes in the image content faster than the update rate, hence, putting the system out of tune. Methods to eliminate these conditions are under investigation.

Motorwav Monitorina in Glasaow

Glasgow is a large urban area in Scotland with an urban motorway system that passes very close to the center of the city. A set of eight fixed view cameras have been installed to provide intensive CCTV coverage through a section with an IMPACTS system installed to automatically monitor traffic. The cameras are color CCD cameras mounted on gantries over the roadway. Images are fed to the control room via a fiber optic network.

The system was installed in Glasgow during the summer of 1993 with a variety of views with up to five lanes of traffic. Additional software has been incorporated to allow individual cell map data from selected cameras to be logged to a data file for selected time periods. At the time, no analysis of data has been carried out , therefore quantitative results are not available. A video data collection exercise during January 1994 showed several examples of the system correctly identifying the buildup of queues. Problems have been reported with strong shadows, due to shadows cast from crash barriers and other stationary objects during periods of low angle sunlight, leading to significant time periods with false alarm settings. Solutions to this particular problem are currently under investigation.

Automatic Traffic Surveillance in the PLEIADES Project

The Paris London Evaluation of Integrated ATT and DRIVE Experimental Systems (PLEIADES) is part of the DRIVE Research Programme. The Automatic Traffic Surveillance (ATS) system has been installed into Maidstone Traffic Control Center and provides information on four separate CCTV images. This information will be used both in the Control Center and passed onto the Traffic Information Center via the PLEIADES Information Controller (PIC) and data communications link. Instead of remote PCs there is a duplicate display of the Engineers workstation that is shown in the Control Office on a single computer monitor.

The ATS system communicates data at regular intervals to the PIC. Any alarms that get raised or cleared during normal processing will get communicated to the PIC as they occur. The PIC uses the information received to display a concise picture of a variety of information about the highway region.

The ATS system uses video from CCTV cameras taken from the existing Control Office Camera Multiplex matrix, while not interfering with its normal operation. When a camera is taken under manual control, the processing of the data for that image is suspended until the camera is returned to its preset position.

Data collection, including time-lapse video, is being recorded from June 1994 to the end of September 1994. Initial results show that some successful detection have been made but that a number of false alarms can be highly variable. For one particular week in July two cameras showed only three false alarms in the 7-day period, but an adjacent camera had more than 200 false alarms in the same period.

4.3.3.3 Japan

The current traffic control system in Japan is operated by a series of control systems consisting of various traffic surveillance technologies, traffic signal controllers, and traveler information services.

The Japanese IVHS program is quite extensive and involves close cooperation between industry and government. An ATMS/ATIS infrastructure has been installed in much of country, and auto makers have been offering navigation systems since 1987. Several government agencies have played a key role in the development and testing of IVHS systems, including the Ministry of Construction, the Ministry of Posts and Telecommunications, the Ministry of International Trade and Industry, the Ministry of Transport, and the National Police Agency. Japanese IVHS programs include:

+ Japan Digjtal Road Map Association
+ Comprehensive Automobile Control System (CACS)
+ Advanced Mobile Traffic Information and Communication Systems (AMTICS)
+ Road-Automotive Communication System (RACS)
+ Vehicle Information Communication System (VICS)
+ Advanced Road Traffic System (ARTS)
+ Urban Traffic Control System (UTCS)
+ Super Smart Vehicle System (SSVS)
+ Personal Vehicle System (PVS)
+ Advanced Traffic Information Service (ATIS)

Applicable surveillance research projects are briefly discussed in this section, including several that are under way to evaluate the accuracy of optical sensors and develop improved data processing methods.

Advanced Road Traffic System (ARTS)

ARTS is an infrastructure-oriented ATIS program aimed at increasing the effectiveness of vehicle-to-roadside communications with a special emphasis on relieving poor visibility conditions. The program builds on technology developed in RACS and is sponsored by the Ministry of Construction. Prospective elements include:

- + Automatic Toll Collection
- + Road Surface Detection Systems
- + Road Alignment Information Systems
- + Surrounding Object Detection Systems — meant to decrease single car accidents during poor visibility conditions
- + Vehicle Headway Control System — involves vehicle-to-vehicle communication via buried roadside cable and automatic control of vehicle operations
- + Traffic Flow Guide/Control System — allows drivers to select optimal routes and reduces congestion

Experiments are currently under way on guide lighting systems for surrounding object detection, buried roadside cable, and vehicle headway control systems.

Urban Traffic Control Svstem (UTCS)

The Japanese Urban Traffic Control System (UTCS) was developed by the National Police Agency (NPA) to improve the function and performance of traffic control systems. There are four functional areas:

- + Integrated Traffic Control System (ITCS)-includes traffic signal control, improved transmission of information to drivers, and automatic toll collection
- + Advanced Mobile Information System (AMIS)-includes two-way communication between vehicle and roadside, and route guidance
- + Mobile Operation Control System (MOCS)-includes automated vehicle tracking and police dispatch
- + Public Transportation Priority System (PTPS)-includes traffic signal control for priority of public vehicles, and in-vehicle transportation information

Current plans are to install UTCS in several key areas for the first phase then lead into covering the entire country.

Reflecting Type Optical Vehicle Sensors

The reflecting optical vehicle sensor is a device which performs vehicle detection by using a light projector and receiver installed above the road. The sensor also performs two-way communications between the roadway device and in-vehicle communication equipment. This provides the capability of collecting appropriate vehicle travel information and providing traveler information services.

Currently, a study is under way evaluating the performance of the reflecting optical vehicle sensor [Sunachi and Imaizumi, 1994]. The optical vehicle sensor was developed to provide both vehicle detection data to the traffic control center and traveler information services. The sensor projects infrared radiation onto the road surface and stores the reflected radiation levels obtained when no vehicles are present. When a vehicle enters the sensed area, the reflected level varies. The sensor processes whether the reflected level is more or less than a predetermined level. Vehicle presence is detected when the predetermined, reflected radiation levels are matched.

Testing of the sensor’s ability to detect vehicle presence and provide traveler information has been conducted in Yokohama City and Sapporo City. Test data was evaluated based on the ratio of the total number of error frames to the total number of received frames of information. The testing criteria was for the Frame Error Rate (FER) to be less than 0.01. Test results showed that the FER was indeed less than 0.01. However, the sample data provided was extremely limited. Data collected at Yokohama City was for a total of 160 test runs and data collected at Sapporo City was for 13 test runs.

Optical Vehicle Detection Using the Range Finding Method

Optical vehicle detectors are used in the Universal Traffic Management System (UTMS). They provide vehicle detection and two-way communications with in-vehicle communication units. Toshiba is upgrading the detector’s sensitivity to passing vehicles by incorporating optical range finding methods [Koyama, et ***al,*** 1994].

These optical vehicle detectors sense vehicle presence by near-infrared radiation. The time that it takes for the radiation to reflect back to the sensor is stored in memory. A vehicle is detected when this travel time varies. The transmitter and receivers are mounted above the roadway.

The range-finding method uses an oscillator signal as a reference signal. The system responds to a transmission signal from the oscillator, and infrared rays are projected from the light projector. Reflected rays are received by the light receiver, thus generating a reflection signal. The reflection signal is then sent to a light path differential circuit. The distance component of the reflection signal generated from the light projector varies with the light paths L1 and L2 (see Figure 4-8). Simultaneously, the transmission signal from the oscillator serves as the reference signal for the light path differential circuit. This circuit compares the reflection signal with the transmission signal and calculates the distance component of the reflection signal. With the distance component thus obtained from the two different reflection signals, pulse signals (T1 and T2), having pulse width which vary with the magnitude of the distance component, are sent to the pulse length measurement circuit. This circuit then measures the pulse widths to differentiate between the vehicle and road surface, thus allowing the circuit to generate the vehicle detection signal. Data has shown this vehicle detection method to be relatively accurate. However, no operation field test data is available at this time.

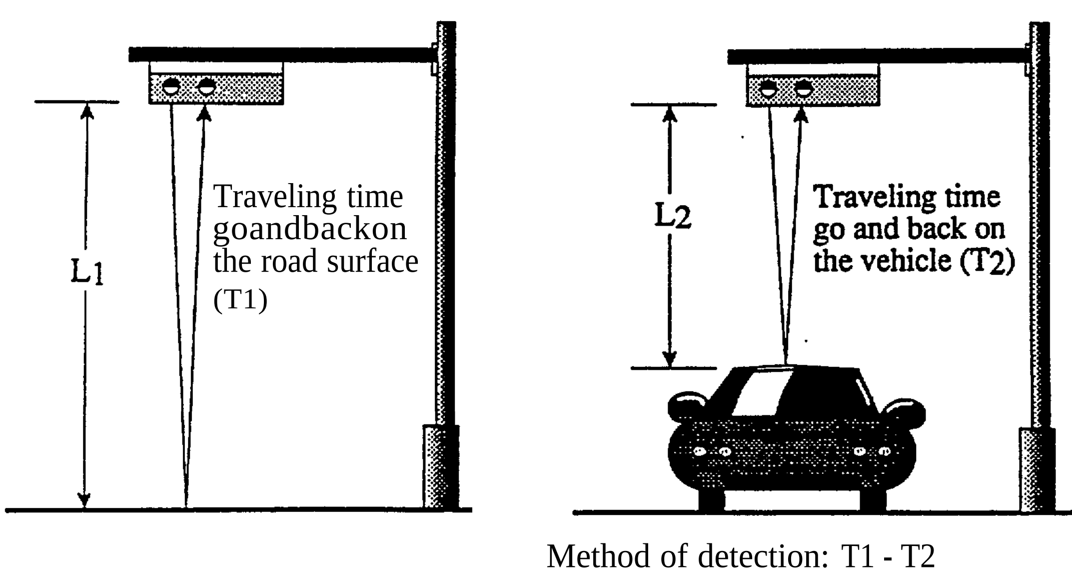

Figure 4-8, Range-Finding Vehicle Detection Concept (Koyama,, et al, 1994)

4.4 SENSOR PERFORMANCE-COST ANALYSIS

This section presents a relative performance-cost comparison of the candidate technologies for use in the system's conceptual design. While all the available traffic detection technologies have been considered as candidates, in reality, functionality is an important criterion for selecting a specific technology for application. For example, if an application requires traffic classification data, the top-ranked sensor, if unable to generate this data, may not be used.

Due to the lack of cost information on many detection technologies, existing studies were used to aid this analysis. The Study Team has found that the cost-effectiveness analysis in the Rockwell's (1994) Early Deployment Study for the Michigan DOT provides relevant information. However, the method used in that analysis was not entirely suitable to the objective of this task. Therefore, the methodology was modified and some of the qualitative performance measures were adjusted to reflect the detector performance results observed by Hughes Aircraft Company (1994).

4.4.1 Analysis Criteria

Earlier in this chapter, the following criteria for technology evaluation were identified: 1) Installation Requirements, 2) Operational Environment, 3) Functionality, 4) Capability and Performance, 5) Availability, 6) Communications Requirements, 7) Maintenance Requirement, 8) Relative System Cost by Application. These criteria are furthered refined for the sensor performance-cost analysis as shown in Table 4-10.

4.4.2 Performance-Cost Comparison

As previously mentioned, the Rockwell analysis was used as the starting point for the sensor performance-cost analysis for this study. This subsection briefly describes the Rockwell analysis and then shows the modifications that were made to support this task.

Table 4-10 Evaluation Criteria for Sensors Cost-Effectiveness Analysis

Evaluation Criteria	Explanations	Criteria Type
1. Installation Requirements	This includes such considerations as pavement impacts, traffic disruption, mounting requirements, etc.	Performance
2. Weather Durabilitv	This criterion relates to the physical life of the sensors under various weather conditions.	Performance
3. Environmental Susceptibility	This indicates the impact of the environment and weather (such as temperature, light condition, traffic condition, fog, etc.) on the data accuracy.	Performance
4. Functionality	This indicates the capability to generate the various direct and indirect MOEs produced by the sensors (such as speed, volume, density, classification, queue-length, travel time, etc.).	Performance
5. Data Accuracy	This indicates the accuracy of data produced by the sensor relative to the real-world situation.	Performance
6. Technology Availability	It indicates the maturity of technology.	Performance
7. Public Acceptance	This includes considerations such as potential health hazards to the public and wildlife. These considerations may affect the acceptance of the technology by the public.	Performance
8. Initial and 0 & M cost	This cost reflects the installation costs and Operations & Maintenance Cost of a sensor.	Cost

4.4.2.1 Rockwell Analysis

Table 4-11 shows the seven criteria and corresponding weights used by Rockwell (1994) for its performance-cost analysis.Some criteria are similar to those selected for this SR/T project (refer to earlier Table 4-10).

Table 4-11. Rockwell Evaluation Criteria* and *Weights

Evaluation Criteria	Explanations	Weights
Ease of implementation	Assessment of technical risk	10
Implementation and O&M cost	Assessment of required budgetary funds	10
Upgradeability	Assessment of openness options	8
Environmental Durability	**Assessment of tolerance to the surrounding environment**	8
Satisfaction of Required MOEs	**Assessment of traffic monitoring**	7
Accuracy	**Assessment of sensing repeatability and precision**	6
Proven Technoloav	**Assessment of technolonv field readiness**	6

Table 4-12 presents the alternative sensor technologies considered by Rockwell and the corresponding system costs. The system costs included the capital cost and O&M costs for 20 years. The O&M cost included operations, maintenance, and preventive maintenance costs. The cost calculation was based on a specific design for a four-lane freeway section with an adjacent two-lane ramp (see Figure 4-9).

Each of the candidate sensors was graded for each criterion on a 1-to-10 scale, with 1 being the least desirable. Although numerical values of the costs were available, the study still used the 1-to-10-scale grading for cost. A composite index was calculated using the grades and corresponding weights. Table 4-13 shows Rockwell grades and ranks of the candidate technologies.

Table 4-12. Sensor System Cost (Rockwell, 1994)

Technology	**System Cost (Installation + 20 years O&M)**
Inductive Loop	$194.856
Microwave	$110,928
Laser/Infrared (active)	$148,740
Pulsed Sonic (active)	$108,240
Continuous Sonic (active)	$132,432
Radar	$116,304
Passive Sonic	$105,552
Passive Infrared-Lane Coverage	$135,300
Passive Infrared-Area Coverage	$143,940
Magnetic	$209,760
Machine Vision	$177.293

4.4.2.2 Performance-Cost Analysis for this Project

The following are the modifications to Rockwell's approach and the considerations used in this performance-cost analysis task:

1. Use the criteria developed for this study: The technology assessment criteria were modified for this task as shown earlier in Table 4-10.

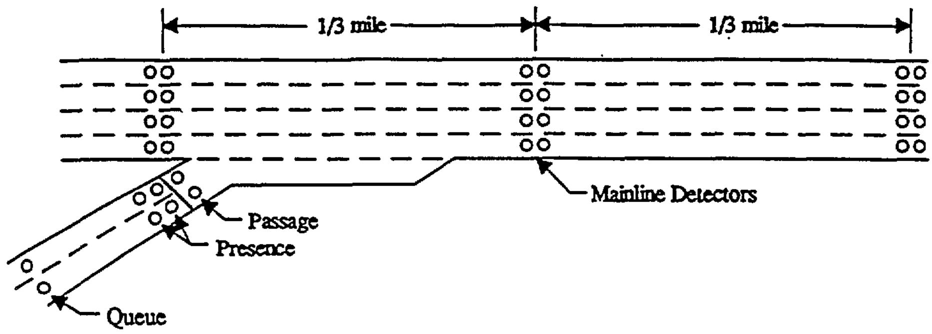

Figure 4-9. Design Configuration Used for Cost Calculation (Rockwell, 1994)

Table 4-13. Grades and Ranks of Sensors

Sensor	Ease of Implem	Cost	Upgrade-ability	Durability	MOE Satisfaction	Accuracy	Proven Tech.	Comp.Index	Relative Ranking*
Inductive Loop	10	6	5	5	6	8	10	390	2
Microwave	8	10	6	6	6	5	4	372	5
Laser/Infrared (Active)	8	8	6	5	6	7	4	356	7
Pulsed Sonic (active)	6	10	5	5	6	5	4	336	10
Continuous Sonic (active)	6	9	5	5	5	5	4	319	11
Radar	7	10	6	6	5	5	4	355	8
Passive Sonic	6	10	7	5	7	5	4	359	6
Passive Infrared-Lane Coverage	8	8	6	6	10	6	4	386	4
Passive Infrared-Area Coverage	7	8	7	7	10	6	3	386	3
Magnetic	8	6	4	5	5	7	10	349	9
Machine Vision	8	8	8	7	10	7	7	434	1

* NOTE: A rank of 1 is the most desirable.
Source: (Rockwell, 1994)

2. Perform a rational analysis: In the Rockwell analysis, the composite index was calculated by the following formula:

   Composite Index = $\Sigma f_i * w_i$, where f denotes the performance factor and w denotes the respective weight.

   Cost was used as one of the grading factors (f) as with other performance factors. It was deemed to have serious flaws. Since all the performance ratings combined indicates the benefits achieved, cost should only be compared with the combined performance index (indicator of benefits). Therefore, cost itself is the biggest decisive factor in the analysis. Analysis methodology was modified to emulate a benefit-cost analysis, where the total benefit is divided by the total cost, instead of considering cost as a performance grading factor.

   Weights to the evaluation criteria were also modified, as the weights used by Rockwell were deemed inappropriate. Equal weights were used in this analysis.

3. Update the performance factors: Some sensor performance factors were modified based on the recent research and operational test results, including Hughes Aircraft Company (1994) and Hartford radar detection system (Mauritz and Stoeckert, 1994).

Analvsis Methodoloav

The analysis methodology emulated the traditional benefit-cost analysis in which the total benefits are divided by the total system costs. First, all the performance-related evaluation criteria, except the Initial and O&M Cost, in Table 4-10 were used for grading individual sensors to obtain a Performance Index. The Performance Index was then divided by the system cost to determine the Performance-Cost Ratio.

The Performance Index, P.I., may be computed as:

P.I. = $\Sigma f_i * w_i$, where f denotes the performance factor and w denotes the respective weight.

The Performance-Cost Ratio for each sensor is then computed using the cost shown earlier in Table 4-12. The higher the ratio, the more feasible is the sensor type.

Findings from Other Projects

The FHWA project entitled "Detection Technologies for IVHS" (Hughes Aircraft Company, 1994) was of utmost importance to this performance analysis. The project included laboratory and field tests of the existing traffic detectors. Although results of the field tests are not available at the present time, results of the laboratory tests were reviewed for possible incorporation in this study. The laboratory test determined the accuracy and reliability of infrared, radar, sonic and magnetometer sensor, by using the outputs of inductive loop detectors as the baseline. Unfortunately, the video image processing technology was not included in the laboratory test.

Table 4-14 shows the accuracy of the various sensors under test in order of their ranks (accuracy is defined as the ratio of the traffic counts by the test sensor to that by inductive loops). It shows that SEO 780D1000 Laser Detector provided the most accurate volume outputs. The table also indicates that the data quality depends not only on technology but also on the model. For example, while two radar sensors, namely, Whelen (Rank #2) and Microwave TC-20 (Rank #4), provided very accurate results, another radar sensor, namely Microwave TC-26, provided poor outputs. Therefore, it is recommended that care should be taken for both in the selection of technology as well as the specific model.

Table 4-14. Accuracy of Detectors

Detector	Type	Accuracy*
SEO 780D1000 Laser Detector	Infrared (Active)	0.996
Whelen TDN -30 Microwave Detector	Radar	1.020
Eltec Infrared Detector (Setting 430)	Infrared (Passive)	0.955
Microwave Sensors TC-20 Microwave Detector	Radar	0.954
Eltec Infrared Detector (Setting 429)	Infrared (Passive)	0.952
Magnetometer (Lane 3)	Magnetometer	1.055
Sumitomo SDU-300 Ultrasonic Detector	Sonic, Pulsed	0.944
Magnetometer (Lane 1)	Magnetometer	1.102
Microwave Sensors TC-30C Ultrasonic Detector	Sonic, Pulsed	1.113
Magnetometer (Lane 2)	Magnetometer	1.774
Microwave Sensors TC-26 Microwave Detector	Radar	2.771

• NOTE: A value closer to 1.0 indicates a more accurate sensor output.
Source: Hughes Aircraft Company, 1994

The reliability of the detectors was measured in terms of Detector Dropout Ratio (D^3R) which accounts for the following failure situations:

+ The test detector returns a zero volume and the inductive loop detector returns a non-zero volume (referred to as undercount failure), in a 15-minute interval.

+ The test detector returns a non-zero volume and the inductive loop detector returns a zero volume (referred to as ghost signal), in a 15-minute interval.

Detector Dropout Ratio was calculated for each sensor on a daily basis. It was computed as

D^3R = 96/(Number of Undercount Failures + Number of Ghost Signals),

where 96 is the number of 15-minute periods per day.

Table 4-15 lists the Dropout Ratios of the test detectors in descending order of their reliability. The table reveals that radar sensors were the most reliable among the sensors tested.

Table 4-15. Dropout Ratios of Detectors

Detector	Type	Dropout Ratio
Wheten TDN -30 Microwave Detector	Radar	74.67
Microwave Sensors TC-20 Microwave Detector	Radar	69.52
Sumitomo SDU-300 Ultrasonic Detector	Sonic, Pulsed	59.29
Eltec Infrared Detector (Setting 430)	Infrared (Passive)	51.69
Microwave Sensors TC-30C Ultrasonic Detector	Sonic, Pulsed	42.89
Eltec Infrared Detector (Setting 429)	Infrared (Passive)	42.00
Microwave Sensors TC-26 Microwave Detector	Radar	41.14
Magnetometer (Lane 3)	Magnetometer	38.77
SEO 780D1000 Laser Detector	Infrared (Active)	38.08
Magnetometer (Lane 1)	Magnetometer	27.24
Magnetometer (Lane 2)	Magnetometer	19.02

Source: Hughes Aircraft Company, 1994

The results from the Hartford, Connecticut operational test (Mauritz and Stoeckert, 1994) was also reviewed. This test is evaluating radar detection technology in combination with CCTV for incident detection and verification. The automated incident detection is based on speed-based algorithms. The system uses 44 radar detectors (wide and narrow beam) and compressed video.

The accuracy of speed estimate was evaluated. The result indicates that the radar provides a fairly good estimate (see Table 4-16).

Finally, Hughes (1994) provided the sensors capabilities of producing necessary MOEs (see Table 4-2).

Table 4-16. Detector Accuracy for Speed Determination

Detector Type and Installation	Average **Difference***
Narrow Beam aimed towards approaching traffic	2.5
Narrow Beam aimed towards departing traffic	2.6
Wide Beam mounted over roadway aimed towards approaching traffic	4.1
Wide Beam mounted over roadwav aimed towards deoanina traffic	2.8
Wide Beam mounted on side of roadway aimed towards approaching traffic	4.5
Lona Ranae detector mounted on side of roadway aimed towards approaching traffic	**10.0**

• NOTE: Difference, in MPH, between the true speed and estimated speed by the radar detector.

Performance-Cost Analysis

Table 4-17 shows the Performance-Cost analysis for the candidate sensors. The bold figures denote the modification over the Rockwell analysis, mainly based on the current research results. Although, there were some data available for sensor reliability as discussed before (in Table 4-15), it could not be used in the analysis because data were not available for all the candidate detectors. However, the reliability factor was taken into account for gaining confidence in the top-ranked sensors from the analysis.

According to this analysis, the top five sensors are: 1) passive sonic (Reliability data not available); 2) radar (Reliability Rank # 1 & 2); 3) pulsed sonic (Reliability Rank # 3 & 5); 4) passive IR - lane coverage (Reliability Rank # 4); and 5) passive IR- area coverage (Reliability data not available).

4.4.3 Conclusions of Performance-Cost Analysis

The performance-cost analysis provides the ranking for the individual sensor technologies. The results of this analysis need to be interpreted very carefully with the considerations:

Table 4-17. Sensor Performance-Cost Analysis

Sensor Technology	**Install. Req.**	Weather Durability	**Environ. Succept.**	Function -ality	Accuracy	Avail- ability	**Public Acceptance**	Perf. Index	Cost, $1000	Perf/Cost Ratio	Rank
Weight	10	10	10	10	10	10	10				
Passive Sonic (Acoustic)	**8**	5	**10**	7	5	4	**10**	490	106	4.62	1
Pulsed Sonic	**8**	5	**10**	6	**5**	4	**8**	460	108	4.26	3
Continuous Sonic	**8**	5	**10**	5	5	4	**8**	450	132	3.41	6
Passive IR - Lane	**8**	6	**6**	10	**6**	4	**10**	500	135	3.70	4
Passive IR - Area	**8**	7	**6**	10	6	3	**10**	500	144	3.47	5
Active IR	**8**	5	**6**	6	**10**	4	**5**	440	149	2.95	8
Radar	**8**	6	**10**	6	**9**	**7**	**5**	510	116	4.40	2
Machine Vision	**8**	7	**6**	10	7	7	**10**	550	177	3.11	7
Inductive Loops	**4**	5	**10**	6	**10**	10	**10**	550	195	2.82	9
Magnetic	**4**	5	**10**	5	7	10	**10**	510	210	2.43	10

NOTE: The bold figures denote the modifications over the Rockwell Analysis.

+ A sensor, even if it is one of the top-ranked sensors, may not be suitable for an application in which required MOE cannot be produced.

+ Technology availability should be a governing factor. A top-ranked sensor, if not technologically matured yet, may have high risks for implementation. However, as technology becomes proven with the operational tests and limited-scale applications, more confidence can be placed on these rankings.

+ The cost data calculated for the analysis is based on a specific configuration of sensors for a freeway application. Therefore, the results may not accurately represent other design scenarios. However, the intent of this analysis was to gain ideas on the relative performance of the sensors. It is recommended that the sensors be evaluated on a case-by-case basis for actual implementation.

With these considerations, the sonic sensors may not be feasible at the present time because of the lack of their maturity and credibility. Yet they have very high performance-cost ratio and should be considered for operational tests. Radar detectors seem to provide a high performance-cost ratio along with an acceptable level of technological maturity and high reliability. However, these can only be used for applications that do not require queue-length information. The possible application may be freeway traffic management, where volume and speed measurements are important. For surface street traffic control, traffic volume and queue-length at intersection approaches are usually very important, and as such, radar is not feasible for intersection application. However, radar may be feasible for the mid-block traffic surveillance requiring only volume and speed information, such as in SCOOT.

The results of the analysis were significantly different from the Rockwell (1994) analysis that yielded machine vision as #1 and inductive loop as#2 sensors, as opposed to ranks #7 and #9, respectively, in this analysis. The main reason attributed to this is the cost consideration in the Rockwell analysis that undermined the high life-cycle costs of these two sensors. However, these two sensors are still very important. Machine vision can provide a number of parameters, such as queue-length and potentially delay information that other sensors cannot provide. With this technology, a vehicle can be tracked at different locations. Furthermore, this technology has the future potential for 'wide-area' sensing instead of point-sensing. With future cost reductions and technological advances, this technology may be viable for wide implementation. On the other hand, inductive loops have credibility and involve a low risk of implementation.

4.5 COMMUNICATIONS TECHNOLOGY IN SURVEILLANCE

The purpose of this section is to assess the existing and emerging communications technologies that may be suitable for the I-95 Corridor-wide surveillance system. The assessment was performed using a number of information sources including FHWA publications, ITS studies, the four IVHS architecture studies, interviews with ITS design consultants, and relevant communications literature.

4.5.1 Existing Communication Technology

Communication technologies used in traffic surveillance consist primarily of wired and wireless communications media. The wired communications medium are predominantly fiber optics, leased telephones, copper wire, twisted pairs and coaxial cables. Packet radio, terrestrial Microwave, Spread Spectrum Radio and Satellite communications dominate the wireless medium. The following paragraphs describe each of these communications medium. The general characteristics of these communications medium are summarized in Table 4-18.

Fiber Optics

The fiber optic cable consists of an inner silica glass core surrounded by a cladding which is also made of silica. The cladding has a higher refractive index than the core resulting in the light waves propagating down the cable to be reflected within the core. The core and cladding are protected by a jacket made of high density polyethylene. Overall cable diameter varies from approximately 4/10 to 7/10 of an inch. Cost of cable ranges from approximately $1 to $6 per foot based on the number of fibers in the cable (telephone interview with Belden Cable Co., December, 1994).

There are two types of fiber, single mode (SMFO) and multimode (MMFO). Multimode fiber is normally used for point-to-point data communication and accounts for less than 10 percent of stock manufactured. MMFO cable is usually used for short distances of up to 2000 feet. SMFO is normally used for backbone data links, and provides higher data rate capabilities. Hardware which are to be purchased, however, should be compatible with both forms of fiber cable.

Table 4-18. Communication Characteristics

Communication Media	Bandwidth	Repeater Spacing	Transmission Rate	Voice Channels	Video Channels	Data Channels	Comments
Fiber optics SMFO	< several GHz (1)	40-50 miles	<several Gbps	100	< 16	100	Number of channels based on multiplex capability
Fiber optics MMFO	500 MHz (1)	1-12 miles	<several Gbps	100	< 16	100	Number of channels based on multiplex capability
Copper wire twisted pair	2.7 KHz	9-15 miles	< 9.6 kbps	24	1 (2)	(3)	Non-video
Coaxial cable	<300 MHz	1-3 miles	cl0 Mbps	100	<50	(3)	One-way comm. only
Cellular packet radio	30 KHz	N/A	1.2 kbps (9.6 kbps data)	1	---	(3)	
Terrestrial microwave	10 MHz (4)	40-50 miles	< 40 Mbps	100	c 16	(3)	Requires FCC license.
Radio (800 Mhz)	25 KHz	15-30 miles	e9.6 kbps	1		(3)	Requires FCC license
Satellite	(5)	N/A	<50 Mbps	100	1	.	Microwave to/from satellite

Source: Stallings, 1985

(1) Bandwidth for fiber-optic cable is indirectly proportional to transmission distance.
(2) Compressed only. Have one T-l capability on copper wire and compressed video can provide good operation on as little as 1/4 of a T-l.
(3) The number of data channels available reflects a trade-off between the achievable transmission rate, message size and format, and the number of applications (clients) to be served.
(4) Up to 220 MHz possible, but bandwidths above 10 MHz require a special waiver from the FCC.
(5) Bandwidth for satellite microwave varies depending on service.

Fiber-optic cables may be installed aerially, direct burial, or pulled though a conduit. Installation in conduit seems to be the more common installation. Although cable pulls of up to two miles are possible under ideal conditions, the normal installation would have four handholes or manholes per mile. Cost of pulling cable is approximately $1 per foot [USDOT, April 1993].

Fiber optics communication systems use a beam of light generated from a laser diode, which travels (propagates) through a glass fiber in serial manner. The beam is pulsed with wave lengths ranging between 850 and 1550 nanometers. The pulses are caused by a turn on/off process which represents the logic state of the transmitted data bits. An injection laser diode (ILD) converts electrical energy into optical energy for transmission. A photodiode, which is a photon counter, reconverts the optical information to digital data.

Although inexpensive modems can transmit data over a dedicated pair of fibers for moderate distances, normally multiplexers are used to transmit the range of video, data, and audio signals over a fiber backbone network. An area of 24 to 30 km radius can be served by fiber optics without having to use repeater or regenerators. Fiber optic repeaters do not amplify the signal but convert it back to original electrical form then reconvert it again to an optical signal.

Attenuation is defined as loss in signal strength as the signal passes through a system. Normal loss for a SMFO is 1/4 db/KM and for a MMFO, the loss is 1 db/KM.

Data rates of up to 2.4 giga bits per second can be accommodated by using time division multiplexing. Multiple channels of data can be transmitted at extremely high speeds resulting in extraordinarily high through-put. Transmission range is normally not a limitation if repeaters are used. Optical fibers are essentially immune to external electrical disturbance or noise.

There are four recognized “communication network topologies” in use today in transportation surveillance and control systems:

1. Unprotected ring: closed loop, uni-directional.

2. Protected ring: two unidirectional communication rings are used to allow each node to communicate with every other node if a cable is cut.

3. Linear drop: nodes connected in a string with data dropped off or picked up at designated nodes.

4. Star: communication links radiate from a source node to multiple secondary nodes. Often, the topologies are combined. The protected ring topology is the preferred fiber-optic backbone system (which is interfaced with other media such as coax and leased telephone lines).

Rapid advancements in the fiber optic technology have caused the price of installing fiber optic cable to decline. In addition, several CCTV companies and other communication companies such as AT&T have spare cables available for lease or co-use. This can be a very valuable alternative for jurisdictions with limited budget and can produce savings in installation cost.

Many states, Maryland, Connecticut, New Jersey, New York, to name a few, have existing and/or, planned uses of fiber optics cable in communication systems for traffic surveillance and control.

The advantages of fiber optic communications are:

+ Fast delivery of data
+ Large volumes of data can be processed
+ Low outside electrical interference

The disadvantages include

+ High costs of trenching and installing conduit
+ Considerable time required for design and construction

Leased Telephone Lines

A leased communications telephone network provides an alternative to jurisdiction-owned cable for use in many traffic surveillance locations. Leasing is available from Local Exchange Carriers (LEC), long distance carriers such as AT&T, cable TV providers, and metropolitan area network vendors. Each of these vendors operates under tariffs filed and approved by state regulatory agencies. Authorized tariff charges may include a one time charge of installation and hook up, a monthly charge for line and system use, and subsequent line conditioning costs.

Many existing traffic control applications use low speed modems (e.g., 1200 to 9600 baud) for communications over voice grade circuits. This transmission can be uni-directional (half-duplex) or bi-directional (full duplex). Usable bandwidth of a typical voice grade line is approximately 2700 Hz and data rates of 9600 bps and higher can be achieved. Normally the voice grade line is used only as a point-to-point connection. If more than one line is returning to the host, a line multiplexer can be used at the privately owned switching center and/or at the host site. Demultiplexers are then also required.

Digital line operations are more commonly associated with larger scale data transmission efforts. Private line data service provides for duplex transmission of digital signals using digital facilities. Synchronous speeds of 2.4, 4.8, 9.6, or 56 Kbits per second can serve point-to-point communications of field devices.

"T1" service within the network refers to a commercial Digital Signal Type 1 (T1) formatted signal which carries 24 digital voice or data channels, or combinations thereof.

The advantages of using leased telephone lines are:

- Minimum up-front capital costs.
- Quick start-up time.
- Private system trouble shooting and maintenance repair.
- Insured system quality.
- Provides "interim" communication medium while planning future changes in needs.
- Low or no maintenance costs.
- Adaptable to all environments, ease of installation.

The major disadvantages are:

+ Little control over monthly fee increases.
+ Limited bandwidth.

Twisted Pair Cable

Twisted pair cable (often referred to as "copper") is currently the most widely used communication medium for traffic surveillance and control related applications. Uses reported include voice, ramp metering, traffic counting, weather and pavement sensors, and variable message signs. It is often the backbone of the telephone systems and the workhorse for intra-building communications [Stallings, 1985].

A twisted pair is made by twisting together a pair of individually insulated copper wire. The twisting reduces noise and interference. Typically a number of these pairs are bundled together into a cable by wrapping them in a tough protective sheath. Such cables are available in 6, 12, 18, 25, 50, 75, 100, 200, 300, 400 and 600 pair sizes. The cables are directly buried or positioned overhead on utility poles and can be installed in underground conduits.

Attenuation is a primary concern for this medium It is a function of distance and wire size, with smaller wire sizes and greater distances resulting in greater attenuation. Repeaters are therefore usually required every 9 to 15 miles, depending on wire size and other variables such as transmission frequency, transmission levels, and receiver sensitivity [Centennial Engineers, Inc., February, 1994].

Because of limited bandwidth(2700 Hz), the twisted pair cable is not the medium of choice for transmitting full motion video, but there is promise for its use in transmitting compressed video. When twisted pair is used in differential modes (RS 422 interface) data rates up to 10 megabytes per second over a distance of 40 feet can be achieved. Twisted pair wiring is primarily used as a point-to-point connecting medium.

The RS485 tri-state driver interface allows multiple surveillance devices to share a single communications line using twisted pair wiring; a technique known as point to multi-point based type architecture.

Twisted pair cables are relatively inexpensive to install and easily adaptable to different routing configurations. However, their disadvantages include:

+ Limited in bandwidth, distance, and data rates.
+ Need repeaters/amplifiers.
+ Susceptible to noise and interference..
+ Attenuation characteristic varies depending on wire size.

Coaxial Cable

Coaxial cable systems, commonly known as "coax" operate with a carrier frequency of 5 to 350 MHz. Data signals, including digital data, voice, analog data, full motion video, and compressed video, are modulated and transmitted along the cable. Transmission rates range from 1200 bps to over 10 Mbps.

The cable consists of a center conductor, which is typically copper clad aluminum, within an outer cylindrical aluminum conductor, which is aluminum, separated by an insulator. Cable size ranges from 1/4 inch in diameter for typical local drops to 3 inches for trunk cable. A 1-inch diameter cable is probably the practical maximum for surveillance applications, due to the difficulty in working with larger cables particularly in overhead installations. Larger cables also require substantial bending radii, resulting in waste and higher installation costs.

Multiple channels on a single line can be achieved by applying various carrier frequencies. Typical channel bandwidths are 6 MHz and may be further subdivided for digital data transmission rates as high as 7.5 MHz. Frequency Division Multiplexing (FDM) techniques are used for channels and Time Division Multiplexing (TDM) for the data on a channel.

Coaxial cable itself is largely immune to noise. However, noise can enter through connectors unless they are carefully manufactured, installed and maintained. Once noise is present in coaxial cable, it is amplified by repeaters along with the signal, resulting in no improvement of signal to noise ratio. Thus, it is important to prevent noise from entering the connectors.

For dedicated cable systems, repeaters may be used, spacing approximately 1/2 mile to 1 mile apart. Since the repeaters amplify the signal along with the noise, coaxial system is usually limited to a maximum range of 30 to 60 miles, depending upon the transmission frequencies and temperature, both of which affect the signal attenuation.

Coaxial cable systems are used for many different purposes in transportation. The Shirley Highway Extension in Virginia uses coax cable as the communications backbone in traffic control and surveillance. The George Massey Tunnel CCTV system in British Columbia uses coax as a distribution system; ATSAC (City of Los Angeles) uses coax in their traffic signal control system for distribution of data [USDOT, April 1993].

The advantages of coax cable are its ability to transmit a variety of signals that support traffic management functions. It is also largely immune to outside electrical interference. The disadvantages include:

+ High skill levels required for testing and maintenance
+ Splicing is sensitive
+ Supporting technology may be waning
+ Short distance applications

Packet Radio

Packet radio systems operate on frequency-pairs in the HF, VHF, UHF and microwave frequency bands via radio base stations and antenna. One frequency is used to transmit and the other to receive. Each base station may serve an area with a radius of 10 to 20 miles as a connection between a backbone communications network and the specified destinations.

The data is packetized and transmitted using modulation techniques such as Frequency Shift Keying (FSK). Data can be transmitted at rates of up to 256,000 bits per second depending on the operating frequency band, and can accommodate voice, digital data, and compressed video. Each packet sent is acknowledged by the receiving node. Individual remote units are uniquely addressed and can be configured to respond only when requested to do so from the master.

This mode of transmission induces excessive link turn-around times since there are four transmissions required: a request, an acknowledgment of the request, a response, and an acknowledgment of the response. Other transmission protocols such as Aloha and Carrier Sense Multiple Access (CSMA) are used in packet radio networks.

UHF frequencies can generally be obtained for use by local governments with a range of 20 to 30 miles using 2.5 watts power units and simple antennas, with a central antenna placed about 100 feet above the average terrain and direct line of sight access. Line of sight should be maintained to the extent possible for efficient transmission, but this requirement is less important with the lower frequency packet systems.

The packet radio architecture and pricing plan adapts best to transmitting short message bursts and not for file transfers or continuous communication between two end points. The costs associated with packet radio including sign up fees per terminal, with minimum monthly charges and small transmit fees.

This type of system should not be considered as a primary communication system for surveillance, but as secondary links, particularly where the terrain makes the use of land-lines difficult.

The advantages of packet radio are:

+ Designed primarily for data transmission
+ Cost effective for short messages
+ Can eliminate the need for leased or owned land line
+ Competitive providers
+ Minimal front-end capital costs

The disadvantages are:

+ Limited to services provided by local subcarriers
+ Not cost effective for continuous communication or lengthy file transfers
+ Effective service may be limited to urban areas
+ Inherent design delays in delivering transmitted packets

Terrestrial Microwave

Terrestrial Microwave operates in the 926 MHz to 40 GHz band, as a point-to-point communication method on a line-of-sight basis. Transmissions are one-way in nature, requiring separate frequency for inbound and outbound communications. A frequency pair allows transmission in both directions at the same time. This medium can transmit data, voice, and video between two points. It can be used as a trunk or single link system. An FCC license is required.

All microwave frequencies are attenuated by the atmosphere with attenuation directly related to frequency. Snow, rain, and fog also interfere with transmissions. The range of transmission is normally only a few miles without a repeater. For applications requiring repeaters, repeater stations are typically located approximately ten miles apart in urban areas.

Microwave systems use both analog and digital transmission techniques. Analog systems typically use Frequency Modulation (FM). Digital systems use Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), or Phase Shift Keying (PSK). Microwave is normally utilized for multiplexing analog voice circuits and live video applications. Multiple channels can be supported with data transfer rates of up to 40 Mbps at distances of up to 50 miles.

Cost of one point-to-point link can be as much as $75,000. [Rockwell International, September, 1993]. Microwave tends to be more expensive in comparison with other communication technologies due to equipment costs at both intermediate and end points.

The advantages of this communications technology include:

+ Useful as a point-to-point trunk.
+ Can transmit data and a limited number of full motion video channels.
+ Can be used to control groups of traffic control devices.
+ Can use both analog and digital transmission.

The disadvantages are:

+ Requires line-of-sight path.
+ In most cases FCC license is required.
+ Operating frequency depends on FCC assignment.
+ Channel availability limited.
+ Possible interference due to rain, snow and atmospheric effects.
+ May require antenna tower.
+ Available bandwidth usually limited.
+ Long start-up design and construction time may be required.
+ Substantial up-front capital costs required.

Spread Spectrum Radio

Spread spectrum refers to a communications technology that spreads a signal bandwidth over a wide range of frequencies at the transmitter, then compresses the signal to the original frequency range at the receiver. This is an application of Code Division Multiplexing (CDM).

The receiver can successfully decode a spread spectrum signal even if the noise level exceeds the signal level. The data transfer rate is the same as conventional radio. Receiving networks can be intermixed since each network is uniquely coded and thus can work within the same band.

There are two spread spectrum techniques currently in use: direct sequence and frequency hopping. Line of sight restrictions generally apply to both techniques.

Approximately 30 nodes can be accommodated on a single frequency which operates in the 902 to 928 MHz range. This range does not require licensing by the FCC. The receive/transmit nodes have to be designed to operate in “cells”. Nodes are slave to a “head-end” radio connected to the central facility. Adjacent cells use different frequency channels.

Messages are transmitted and received in frames. A typical frame time is one second. At the beginning of the frame the central site sends to the head-end messages for all the nodes. The head-end radio transmits these messages in a single packet. Each node receives the packet and removes the message coded for that site only. The addressed node responds to the head-end radio to complete two way communications. The head-end collects all the responses and forwards them to the central site.

Data transmission rates of 200 KBPS can be achieved. Spread spectrum radio has far ranging applications in surveillance application where land lines are not physically or economically feasible. The city of Anaheim, California, is planning to evaluate the use of spread spectrum radio as a communication link between the surveillance stations and its traffic management center. This link will be used to transmit real-time data and video.

The advantages of spread spectrum radio include:

+ Very flexible installation.
+ Does not require FCC approval in 902-928 MHz band.
+ Works extremely well in a high noise environment.
+ Uses low transmitter power.

+ Can be used in a mixed system of wired or radio interconnected controllers.

+ No land line interconnect requirement.

+ Potential for broad range of traffic surveillance system applications.

The disadvantages include:

+ This represents a new technology in the traffic surveillance area, hence, is uncertain.

+ Uncertainty of the 902 to 928 MHz band for reliable use due to interference from other users that are allowed to operate in this frequency range.

+ Higher bandwidth required than radio fixed frequency transceivers.

+ Requires external antenna and cable.

+ Requires more sophisticated equipment and specialized technicians..

+ Line of sight requirement.

Satellite Communications

Satellite communications use earth stations to transmit and receive data via a geosynchronous satellite positioned approximately 22,300 miles above the earth. The FCC allocates frequencies for fixed service satellites in the C and Ku band. For C band, the uplink frequency band is from 5.925 GHz to 6.425 GHz and the downlink from 3.700 GHz to 4.200 GHz. The Ku band uplink frequency band is from 14.0 GHz to 14.56 GHz and its downlink from 11.7 to 12.2 GHz.

Communications generally require high transmission power and large antennas. Earth stations are therefore required at transmit/receive sites. The function of the earth station is to modulate the baseband signal to the appropriate power and transmission frequency and then to radiate the signal to the satellite. The satellite shifts the received signal's frequency to the appropriate down-link frequency, amplifies it, then radiates the signal back to earth receiving stations.

The bandwidth of the satellite is 500 MHz with data rates of up to 45 Mbs. It should be noted that there is a propagation delay of about 240 to 300 msec from the time one earth station transmits to the time another receives the signals. This is due to the long distances involved. Also, satellite communication is strictly a broadcast medium. Stations can transmit to the satellite and a transmission from the satellite can be received by many stations. Implications are that this medium would be suitable for a wide surveillance area, such as the I-95 Corridor.

Until now the focus of traffic surveillance has been mainly local (i.e., not much coordinated activity across jurisdictional borders). So satellite communications has not been found to be a cost effective means because of a sizable installation cost. Now that there is more cooperation across state boundaries, satellite communication might see greater use.

The Federal Highway Administration through the Pennsylvania Department of Transportation (PennDOT) has launched a program to implement a Traffic and Incident Management System (TIMS) in the Philadelphia area. A unique part of the system is the Mobile Satellite Communications Platform utilizing a Very Small Aperture Terminal (VSAT) Ku band satellite system. The platform is envisioned to provide extended coverage of the existing CCTV surveillance network, restore and re-establish failed communication links within the TIMS network, and transmit data and video from an incident site to the Traffic Control Center (TCC), enhancing PennDOT's incident management capabilities [Urban Engineers, Inc., 1994].

The advantages of satellite communications are:

+ Cost of circuits independent of their length
+ Cost effective for long-haul circuits
+ Downlink signals can be received over a wide area
+ Uplink signals can originate over a wide area
+ Flexibility for "quick setup" or mobile applications

The disadvantages include:

- Not proven cost effective for local type communications
- Limited number of service providers
- Channel leasing costs subject to increases

4.5.2 Communications Standards and Protocols

Interface Standards for Wire Systems

The Electronic Industries Association (EIA) has issued standards for interconnecting all electronic equipment for wire systems. For compatibility, all manufacturers of electronic equipment must adhere to these standards. The two most important standards interfaces are: RS 232 and RS 44914421423.

The RS 232 interface is the most common standard used in the US for serial data transfer. This standard applies to data transmission up to a distance of 50 feet at a data rate of 20 Kilobits per second (kbps). The mechanical specification calls for a 25-pin connector with specific pin arrangements. The electrical characteristics specify signaling types and logic levels. Binary 1 is used to specify a voltage lower than -3 volts (-3V) with reference to a common ground while Binary 0 is used for a voltage higher than +3 volts (+3v) with reference to the same common ground.

One of the most noteworthy limitations of the RS232 interface is its distance and speed characteristics. To make improvements in these areas the EIA issued a set of standards: RS449, RS422, RS423 as described below.

RS 449 defines the mechanical, functional, and procedural characteristics of this new interface. RS 422 and RS 423 define the electrical characteristics. RS 449 is similar to the RS 232 and is intended to exhibit a degree of inter-operability. Mechanically the RS 449 specifies a 37-pin connector for the basic interface and a secondary O-pin connector if a secondary channel is used. The major improvements of the RS 449 is in the electrical characteristics as specified by RS 422 and RS 423. RS422 specifies a balanced (differential) interface and can transmit at higher data rates over longer distances than RS 423, the unbalanced interface. RS 423 provides for data transmission up to 4,000 feet at 1.2 KBPS and 40 feet at 100 KBPS. RS 422 provides for data transmission of 100 KPBS over a distance of 4,000 feet and 10 MBPS over 40 feet.

452.2 Synchronous Optical Network (SONET)

SONET provides standards for fiber optic communications. SONET, defined by the ANSI T1 standard, specifies transmission capacity, optical interconnects, and internal formatted signals in terms of Optical Carrier type N, where N specifies capacity in terms of electrical DS3 data rates. The bit rate of DS3 is 51.84 Mb/s. The benefits of SONET include hardware interchangeability; easier maintenance, which results is lower operating costs; simplified multiplexing; standard optical rates; and true interconnectivity between different vendor equipment.

Leased Telephone Lines

The American National Standards Institute (ANSI) T1 standards define electrical telecommunications standards for North America. These standards cover network facility interface points, transmission speed, signal formats, and standard vendor interconnect specifications. The T1 protocol uses a time reference of up to 50 milliseconds for synchronization. T1 service refers to a Digital Signal Type 1 (DS1) formatted signal and can carry 24 DSO channels or a combination of voice and data. The bit rate is 1.5444 megabits per second.

Radio Access Protocol

The techniques used for packet radio networks can be termed random access or contention techniques. There are three such protocols use: Aloha, slotted Aloha (S-Aloha) and CSMA. Aloha and CSMA have enjoyed extensive use in packet networks. Slotted Aloha is **a** refinement of Aloha.

Whenever a station has a packet to transmit it does so. The station then listens for an amount of time equal to the maximum possible round trip propagation time on the network (twice the time it takes to send a packet between the most widely separated station). If the station hears an acknowledgment during that time, all is well; If not, it retransmits the packet. After repeated failures, it would give up. The receiving station determines the correctness of the packet by examining the Frame Check Sequence (FCS). If the packet is valid, an acknowledgment is issued immediately. A packet may be invalid due to noise or as a result of a collision with packets from other stations. Such collisions are possible due to the random access nature of the network. Because of this fact the maximum throughput achieved with Aloha is only 18 percent of capacity [Stallings, 1985].

Because of this limited throughput, the slotted Aloha (S-Aloha) was developed. With this protocol, time on the channel is organized into uniform slots whose size equals the packet transmission time. A central clock or other technique is used to synchronize all the stations. Transmission is permitted to begin only at a slot boundary. These packets that do overlap will do so totally. The maximum throughput realized with this scheme is 37 percent of capacity or twice that of the basic Aloha [Stallings, 1985].

To further improve throughput efficiency, the CSMA or "listen before talk" (LBT) protocol was developed. With this scheme, if a station wishes to transmit a packet, it first listens to the medium to see if a transmission is in progress. If the medium is idle the station may transmit. Otherwise the station backs off and tries again after waiting for a time period determined from a probability distribution. With this protocol, collisions are rare and occur only when two stations star-l transmission almost simultaneously. Throughput efficiency can approach unity depending on the persistence algorithm used when the medium is busy.

4.5.3 Emerging Communications Technology

Research and development in the area of communications technology has primarily been driven by the ever increasing need for greater system capacity, higher data rates, improved system reliability as well as the availability and cost to the end user.

The rapid increase in the use and everyday acceptance of cellular communications in the last few years has prompted industry and government to satisfy the consumers need to communicate, via voice or data, with anyone, from anywhere and at anytime. Unfortunately there is a severe shortage of spectrum available for the implementation of new wireless technologies for mobile communications. The following sections discuss the current developments in new communications technologies with an emphasis on wireless technology, for use in traffic surveillance.

Laser Optics Open-Air Communications System

In an effort to develop a potential alternative to the use of the global positioning system (GPS) as a basis for vehicle location, research into the use of a laser optics open-air communications system (LOOC) is under way as part of the IVHS - IDEA program [Chand, 1994). This system uses infrared light wave transmitting-receiving terminals which are linked via commercial telephone lines, computer networks or dedicated data network to a traffic information and control center. Highway terminals are mounted on overhead structures (e.g., bridges, roadway signs, dedicated poles, etc.) and a similar terminal is installed within each vehicle. Terminals communicate with each other as the vehicle passes the overhead structure without the requirement to stop or slow down although a maximum velocity has been defined to ensure reliable communications.

LOOC utilizes an electronically directed and focused laser which automatically directs the signaling laser beam into the receiving lens of the other terminal. This technique of controlling the laser saves power, reduces crosstalk and eliminates the potential for harm to the human eye when compared to conventional laser communication systems.

The disadvantages associated with LOOC are its sensitivity to weather conditions (i.e., rain, fog, snow) which greatly reduce transmission distances due to the scattering of the infrared light wave signal. As well, there are currently limitations on vehicle speed (100 km/h) and the size of reliable data exchanges between terminals. Data exchanges of approximately 1 Mbyte can be assured given the following conditions:

+ The highway terminal is mounted sufficiently high and toward the right side of each traffic lane to ensure communication with only the leading on-coming vehicle.

+ Vehicle spacing must be 15 meters or greater.

+ Maximum vehicle speed of 100 km/h must be realized.

+ Error detection codes are used with provision for retransmission as required.

The initial development phase of this research has produced prototype hardware, software and communications protocol. A follow-up Phase 2 project is planned which will involve the field testing of this new technology as part of an automated vehicle guidance system.

Spread Spectrum Radio

Although the concept of spread spectrum communication has been around for a number of years, this technology is seen as a potential solution to the problem of spectrum limitation.

Spread spectrum currently uses the 902 to 928 MHz band, which has been allocated by the FCC for unlicensed use by amateur radio systems, digital portable telephones, and other low-powered devices. By operating in this unlicensed portion of the spectrum the FCC provides no guarantees from interference.

The benefit of spread spectrum is that it is less susceptible, but not immune, to radio interference than other radio communication systems. Instead of transmitting at full power on a single channel, spread spectrum users transmit for very short periods of time on many different channels.

While many potential contenders are watching and waiting for the FCC to release additional licensed channels or to hold license auctions, one company, Metricom, Inc., is already proceeding with plans for wide-area wireless data networks. This low-powered spread spectrum system will operate in the unlicensed 902 to 928 MHz band utilizing Metricom's patented geographic addressing scheme. Some of the advantages of this system include true peer-to-peer communication capability, redundant communication paths, immediate access to the network from any location, low cost, and low-powered transmitters and receivers. The RF data rate is 77 kbps, which will translate into a user data rate in the range of 50 to 60 kbps. Projected monthly user charges range from $2.95 to $19.95 based on the subscribers data rate.

The primary concern with this potential system lies in its use of the unlicensed band, which must be shared with other users. As this band becomes more and more crowded, the potential for interference from other systems increases. This concern has prompted the FCC to allocate an additional 20 MHz of spectrum in the 2 GHz band for unlicensed systems. Another concern is more political than technical. There exists the potential for unregulated companies, such as Metricom, to be in direct competition with licensed operators who are regulated by the FCC and are required to answer to the various states' public utility commissions.

Cellular Digital Packet Radio

Cellular Digital Packet Data (CDPD) has often been touted as being the real beginning of wireless digital communication. CDPD technology essentially overlays the existing analog cellular system, making use of the widely installed cellular phone systems throughout the nation. It should be clarified that CDPD technology has made it possible to move data over wireless networks, but it is not itself a wireless data network. The difference is that networks provide intelligent controllers which monitor the network and route traffic. CDPD, on the other hand,, is strictly a data "pipeline" over which data can be sent. Traffic is directed externally by the end user or an intelligent network switch.

The original concept behind CDPD was established by seven leading cellular service suppliers and IBM, who developed the cellular packet switching protocol. Data rates up to 19,200 bps are possible using techniques to send and receive data over idle cellular voice channels and to "hop" between channels as they become used for voice transmission. Therefore, a cellular operator can provide data transmission service without impacting voice traffic.

Although seen by many as the future standard for wireless data networks, the reality is that CDPD is still without a single "owner" to push for standardization and nationwide implementation. Many cellular carriers have deployed CDPD, which means that services will not be available in all areas. Unless they become as integrated and seamless as existing wireless data services, such as RAM or ARDIS, CDPD systems will not become a major contender in the wireless data marketplace.

Personal Communication Services

An area-wide wireless communication system offers many advantages over wired systems, which is one of the main reasons behind the dramatic growth in the sales of mobile and portable cellular phones. Such service is relatively inexpensive, easy to use and can be used almost anywhere in the nation or the world.

It can be expected that in the near future, cellular services, as we know them, will expand to provide nationwide and potentially worldwide coverage by using satellite systems. It can be assumed that this increase in service will be accompanied by the capability to send and receive data.Although there are several new technologies emerging to allow for transmission of data over cellular phone, a national standard has yet to be established. It would appear that to superimpose the capability for data transmission on a system which was originally designed for analog voice, does not provide the optimal solution.

Personal Communications Services (PCS) is the proposed future for mobile nationwide and worldwide voice and data communications. PCS will be a digital system, not an analog-based cellular system. This greatly simplifies the movement of voice or data through the system and provides the ability for data encryption, error checking, multiplexing, and increased transmission speed.

In 1993, the FCC allocated spectrum in the 1.8 to 2.4 GHz band, and has authorized up to seven different sets of frequencies (two 30 MHz blocks, one 20 MHz block, and four 10 MHz blocks) [Colmenares, May 1994]. Licenses will be issued through an auction process with the highest bidders being awarded licenses in one or more areas of the country. Unfortunately, the FCC decided not to issue nationwide licenses for these services. This is similar to the situation which occurred with the licensing and implementation of analog cellular: there is no one system that will provide instant access under all conditions.

Delays are expected during the bidding portion of the process, since this method of auctioning spectrum is a first for the FCC and the industry. In addition, this portion of the spectrum is already heavily used by point-to-point microwave systems. All of these systems must be relocated to higher frequencies: and the FCC has indicated that the PCS providers must pay the associated costs, expected to be in the billions of dollars. Fully functional PCS systems are not expected to be available for use until 1998.

Some of the major players in the development of this technology include Apple, WinForum, APC, MCI, Time Warner, and many of the existing cellular phone operators.

4.6 TECHNOLOGY ASSESSMENT SUMMARY

Many of the existing vehicle detection technologies continue to be appropriate for deployment in ITS applications. For example, inductive loop detectors, though relatively difficult and expensive to install in existing roadways, offer the advantage of years of experience and familiarity of operation by transportation agencies. Loop detectors provide consistent and relatively reliable traffic data, and the data processing is comparatively simple and well understood. The limitations and problems associated with loop detectors, such as the need to replace loops following resurfacing, are also well known. The problems associated with loop detectors have spurred interest in developing alternative vehicle detection technologies.

Other existing vehicle detection technologies, such as video vehicle detection, microwave radar, infrared, and acoustic sensors, have all been deployed at various levels and with varying degrees of success. Each has particular advantages and disadvantages which must be considered in evaluating technologies for deployment in a surveillance system. For example, video vehicle detection, depending on the image processing technique applied, offers both the capability to emulate inductive loops and to perform more advanced image analysis for direct detection of incidents. However, this capability comes at a relatively high cost, particularly for applications requiring transmission of real-time, full-motion video from the sensor site to a traffic management center. The performance of such systems is also degraded during nighttime operations and adverse weather conditions, in particular, dense fog. Microwave radar detectors provide highly reliable speed measurements, but vehicle presence detection is less accurate, especially in high volume conditions, due to the difficulty in discriminating between closely spaced (high-density) vehicles. Sensor costs are relatively inexpensive, but public acceptance of such sensors is questionable because of popular anxiety about high-frequency electromagnetic radiation. Infrared and acoustic sensors also have unique advantages and disadvantages.

It is the integration of surveillance information from various sensor technologies and other surveillance sources, such as travel time data from commercial vehicles, which has the potential to allow development and deployment of a surveillance system providing the required functionality at an affordable cost. By integrating the information from existing sensor data with data obtained from other sensor technologies in an intelligent manner, traffic management centers will be able to make the best use of the information available.

Finally, when the existing infrastructure is insufficient or simply does not exist, the capital costs associated with deploying a surveillance system can be prohibitive, if conventional approaches are used. Costs for deploying a fiber-optic communication system for carrying traffic data over long distances may prevent the desired functionality. In such situations, alternative, so-called “light infrastructure” surveillance system development approaches are warranted. This approach is being pursued in Canada. This general trend of Canadian transportation agencies facilitates the deployment of cost-effective surveillance systems and provides required functionality by taking advantage of advances in communication technologies and data compression techniques, and by intelligently integrating information from other surveillance systems.

Weight measurement technology is evolving. Weight data are not directly used for traffic management and typically have been used for planning and design. The recent shift to using weight data in conjunction with AVI impacts traffic management by providing an efficient ETTM operation. Existing conventional WIM systems not provide the accuracy needed to support the various uses of WIM data. The use of weight data in law enforcement and toll collection warrants accurate data for individual vehicles. The technology is advancing toward a higher level of accuracy and compactness. Among the evolving newer weight sensor technologies, use of piezo-cable or piezo-film is maturing. Fiber-optic WlMs have been initiated and need rigorous evaluation. Recent research favors the use of multiple weight sensors in the same station to achieve a higher degree of accuracy. This increases the demand for low-cost, compact sensors. Ongoing studies evaluating evolving technologies need to be closely monitored.

The use of environmental sensors for highway applications is relatively new. The current technology provides a full range of environmental data, including air temperature, visibility, pavement temperature, and pavement condition. Less effort has been applied to evaluating the performance of environmental and weather sensors. One report indicate the general satisfaction of the agencies with pavement sensors. The Chapter 3 (Existing Systems Survey) survey also indicated the satisfaction of the agencies with the environmental sensors. The ongoing Idaho Storm Warning operational test is evaluating the effectiveness of commercially available environmental sensors. This test will establish a knowledge base of system performance.

Existing communication technology is rated generally satisfactory for the present needs of the traffic management team in the respective jurisdictions. However, from an ITS perspective, many jurisdictions lack the ability to cope with their future needs of surveillance, collecting, processing, and disseminating traffic data.

The trend in upgrading the land medium is toward the use of fiber-optic cable as the communication backbone. Interfacing to the fiber will be various other media, such as coaxial cables and radio networks. Satellites, in the past, have been used little because of the prohibitive up front installation cost and the time required to implement this technology. However, if the Corridor is envisioned as a network, with each member state as a node, satellite usage may be an affordable option, if undertaken collectively. Emerging wireless technology should provide valuable support for the land-based communication backbone.

The development and deployment of a cost effective surveillance or communication system must consider: the functional intention and requirements; the availability of existing infrastructures, in particular, communication infrastructures; existing surveillance technologies and systems for processing sensor data; the installation requirements and performance characteristics of the technologies; and finally, opportunities for integrating the information available from various surveillance sources.

Finally, technology assessment should be a continuous process and should keep up with the rapid evolution of technology. The assessed technology will drive a concept design which is best suited under current technological capabilities. Continual technology assessment throughout the project life, from system design to its deployment, can provide an efficient utilization of technology.